4. THREATS, STRESSORS, AND EXISTING MANAGEMENT ACTIONS

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In this section we describe various threats and impairments to nearshore and marine ecosystem processes and salmon habitats and functions. We also provide brief descriptions of existing management actions. These materials complete our introduction to the various portions of our conceptual model (Figure 4-1).

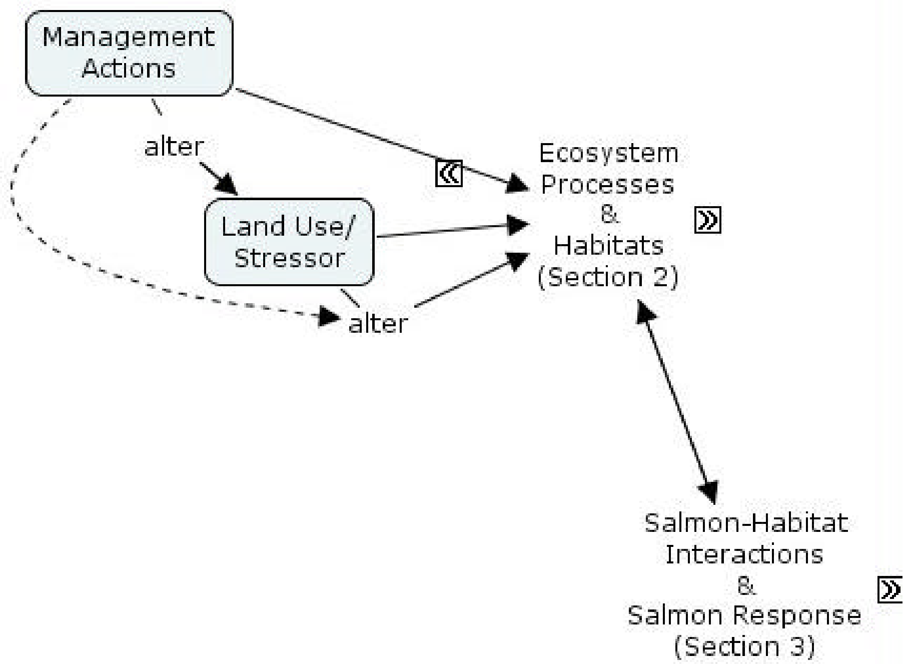


Figure 4-1: **The human stressor and management portion of our conceptual model**

In this section, we briefly discuss some of the historical human activities, policies, and other factors that have contributed to habitat and ecosystem change in the Puget Sound region (Section 4.1); discuss the threats (potential for harm) and impairments (currently degraded or lost function or process) that we believe to be the most critical concerns for region-scale nearshore and marine aspects of salmon recovery (Sections 4.2 to 4.9); and introduce some of the key existing management authorities that can address these threats and stressors (Section 4.10).

Our evaluation of threats and impairments was informed by and followed the organization of, the PSAMP conceptual model (Newton et al., 2000). We considered the relevance of each of the stressors listed in the PSAMP model to salmon viability when viewed at the regional scale, and evaluated the effects of various candidate stressors on the four functions of nearshore and marine habitats for salmon. Our conceptual model (derived from PSAMP) of the associations between stressors (categories of mechanisms of threat and impairment) and human actions is presented in Appendix C. Two overarching considerations were important to our thinking about and review of stressors' potential effects on salmon:

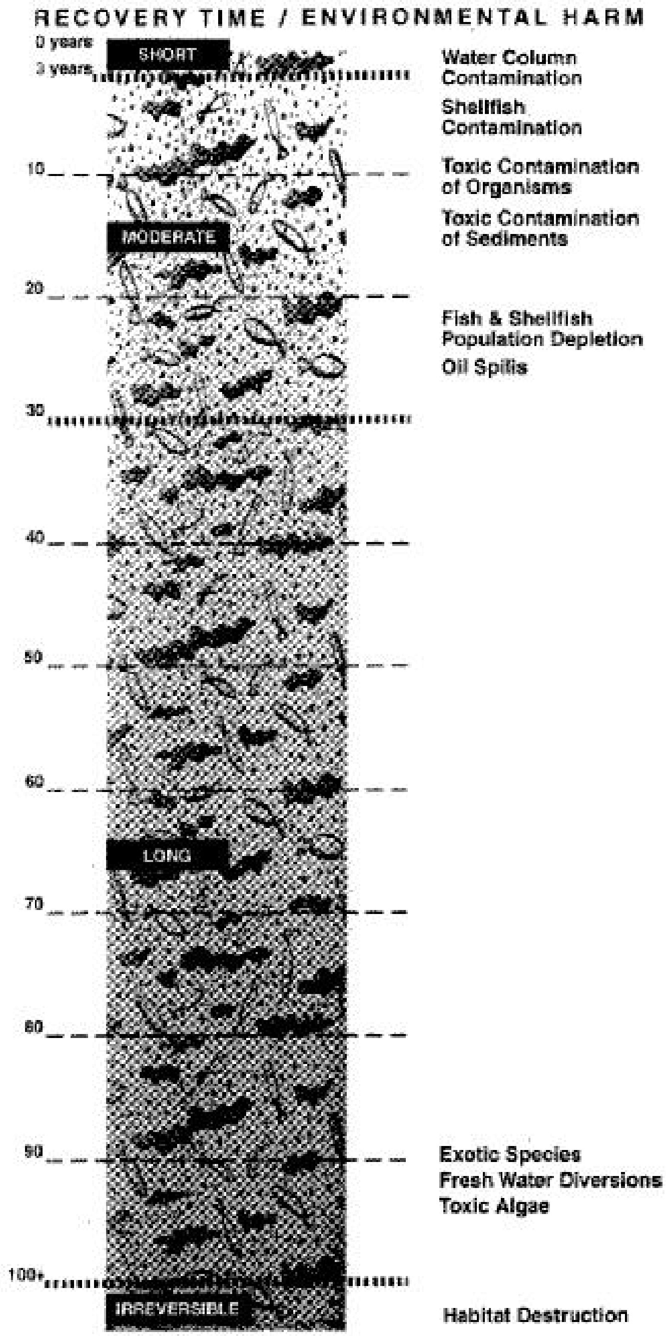
- Human activities impart stressors to the nearshore and marine environment that can persist for varying lengths of time. Often, if the activity causing the stressor is removed, the environment may be allowed to recover or regenerate. The recovery time required to remediate environmental harm can be highly variable. For example, the environment may recover from a stressor such as shellfish contamination in a moderate period of time (3-10 years); whereas the environmental recovery time for a stressor such as habitat destruction may be irreversible (100+ years) (Figure 4-2) (PSWQA, 1994).

- In estuarine and nearshore environments many stressors can co-occur because these areas have been the focus of much human development and activity over the past 150 years. Effects of the multitude of human-induced stressors on salmon are compounded in estuarine areas because the fish are naturally stressed as they use and pass through estuaries due to physiological changes associated with the transition from living in fresh to salt water environments (from Aitken 1998). We presume this compounding of human and natural stresses also confronts fish that accomplish this transition in areas away from the estuaries of their natal rivers.

By acting on the functions that salmon receive from nearshore and marine environments, the stressors discussed in this section can affect the viability of salmon populations in a variety of ways. In some cases, a stressor might jeopardize the viability of a particular life history type within a population and, therefore, limit the population's spatial structure and/or diversity. For example, the loss of river estuary and proximal nearshore habitats can threaten the viability of the delta fry and fry migrant segments of a population even though high quality pocket estuaries may be abundant in the more distant reaches of Puget Sound. In other cases, the same stressor (loss of estuary habitat) may reduce the productive capacity of a sub-basin and thereby jeopardize the abundance and/or productivity of a population.

The following stressors are presented in this section and carried through to a landscape analysis in Section 6:

- Loss and/or simplification of deltas and delta wetlands
- Alteration of flows through major rivers
- Modification of shorelines by armoring, overwater structures and loss of riparian vegetation
- Contamination of nearshore and marine resources
- Alteration of biological populations and communities
- Transformation of land cover and hydrologic function of small marine discharges via urbanization
- Transformation of habitat types and features via colonization by invasive plants



Source: Puget Sound Water Quality Authority and British Columbia Ministry of the Environment, 1994.

Figure 4-2. Recovery time based on a selection of environmental stressors.

4.1 Historical considerations

Human activities and development patterns have modified, and continue to alter, nearshore ecosystems by constraining, redirecting, disrupting or eliminating the processes that control the delivery and distribution of sediment, water, energy, organic matter, nutrients and other chemicals in Puget Sound's nearshore environments. (A more detailed account of these patterns and the motivations behind them is found in Appendix D). These activities and development patterns were driven by the social, cultural, and economic values of the societies, communities, and individuals that resided in or utilized these nearshore marine ecosystems over time. Negative feedbacks from rapid development and resource extraction prompted environmental legislation in the early 1970's corresponding to a similar awakening nationwide. Our more recent commitment to restoration of nearshore processes signals additional changes to the social, cultural and economic values that are currently held by many Puget Sound residents. It is important to acknowledge that many impairments to Puget Sound's nearshore landscape occurred through practices that were considered appropriate for the time and reflected the social, behavioral and cultural values held by the people. Our ability to restore nearshore habitats and functions will similarly be aided or obstructed by those values now.

4.2 Loss & simplification of estuaries and wetlands

Stressor: Loss and simplification of river mouth estuaries, deltas, wetlands

Examples of *activities* contributing to this stressor:

- Industrial and residential development,
- Agricultural activities (e.g., diking, filling, revetments, tidegates, other water control structures),
- Channelization,
- Construction activities (e.g., jetties, training walls).

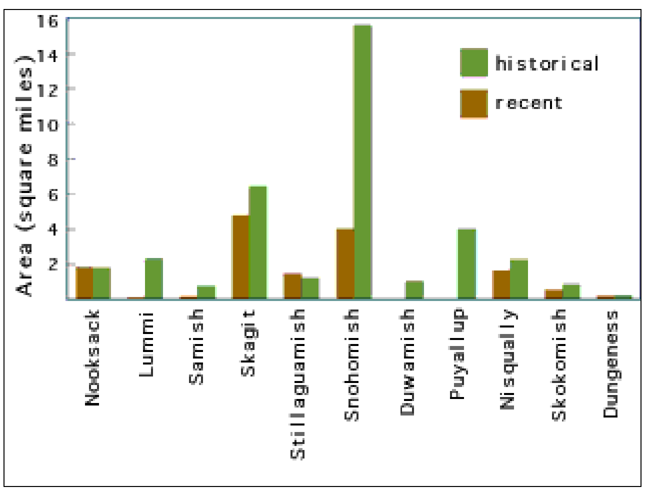
Working Hypotheses

1. Activities such as diking and straightening of estuarine/lowland channels results in lost floodplain area, as well as constrained and accelerated movement of water through the channels,
2. This can lead to increased erosion potential by transporting sediments and organic material, and ultimately an altered arrangement of drainage channels,
3. These changes reduce or degrade the functions estuarine habitats provide for juvenile outmigrant salmon (e.g., feeding and growth, refuge, physiological transition, migratory corridor), especially those of the delta fry life history type.
4. Agricultural and development activities impact sub-adult and adult anadromous bull trout by impacting rearing and migration, and overwintering habitats.

Effects on processes and habitats

Humans throughout the ages have populated large and small estuaries in Puget Sound. Historically, such locations were optimal for a variety of reasons, including habitation, commerce, food, and access to Puget Sound waters. However, habitat conditions of the major (and lesser) river estuaries of Puget Sound have changed considerably over the last century.

Estuaries in Puget Sound are regions that attracted early agricultural and industrial development and because of activities such as diking and filling, greater than 73% of the river delta wetlands have been lost in the last 100 years (People for Puget Sound 1997). Bortleson et al. (1980) compared historic and present-day maps and reported the loss of subaerial wetlands and intertidal areas for 11 major Puget Sound estuaries. A majority of the 11 estuaries showed a loss of *subaerial* wetlands, of which three estuaries (Lummi, Snohomish and Puyallup) exhibited a significant loss totaling 5km^2 or more (Bortleson et al., 1980). Diking was identified as the primary causative agent. The Nooksack and Stillaguamish estuaries exhibited a slight increase in subaerial wetland area. The Lummi, Skokomish and Dungeness estuaries showed relatively minor loss of *intertidal* area, whereas the Duwamish and Puyallup estuaries exhibited nearly a complete loss of intertidal area (Bortleson et al., 1980). Extensive dredge and fill operations were identified as the primary causative agent. The extent of the loss of wetland habitat from the late 1800's through the 1970's for many of the major estuaries listed in Section 2.3 is shown in Figure 4-3**.**



Source: People for Puget Sound's (1997) *The Loss of Habitat in Puget Sound* (after Bortleson et al. 1980).
Figure 4-3. Historical changes of wetland area in major river deltas of Puget Sound.

The amount of habitat loss between these large river estuaries is variable, as are the categories of land use prompting the decline. For example, the Duwamish and Puyallup estuaries are proximate to our largest urban centers, and as a result of human activities such as industry these estuarine habitats have experienced considerable losses. The change in wetland habitat area between historical and current (1970's) condition in the Snohomish estuary is substantial. However, many of the agricultural lands made possible by historical diking are no longer actively worked. Thus, the Snohomish estuary offers significant opportunity for restoration.

Collins et al. (2003) utilized archival sources and field investigations to create GIS maps of the historic riverine environment for several systems in north Puget Sound. Prior to extensive modification of the landscape by settlers, the large floodplain wetlands and extensive estuarine marshes "accounted for nearly two-thirds (62%) of the valley bottom" of the Snohomish River (Collins et al, 2003). The Nooksack mainstem exhibited a similar distribution of habitats, historically. A less complex channel pattern now exists for the upper Nooksack mainstem and the Skykomish River, due in part to levees and isolating meanders (Collins et al, 2003). Historically, estuarine wetlands were extensive in the Skagit-Samish delta, consuming an area more than twice that of the Nooksack, Stillaguamish and Snohomish deltas, combined (Collins et al, 2003). Diking and draining of wetlands has reduced the area. The loss of side channel regions and riparian vegetation in floodplains and estuarine areas can be attributed to such activities as agricultural practices (USFWS 2004). Diking and tidegates negatively affects tidally influenced habitats by limiting saltwater exchange with historic estuaries, such as with the Skokomish River (USFWS 2004). Fish passage and prey species can be impacted.

Effects of dike construction and marsh conversion are often most obvious on the landward side (e.g., converted land). Less visible are the *seaward* effects of such an activity. Hood (2004) studied the *seaward* effects of dike construction and marsh conversion on estuarine marshes and tidal channels in the Skagit River delta via analysis of historical photos. Three separate areas were studied: Wiley Slough area, South Fork Skagit delta, and North Fork delta. Hood (2004) reported "dikes indirectly affect sediment dynamics and channel geomorphology in seaward areas as a consequence of tidal prism loss that results from the dikes directly excluding tidal waters in landward areas." More tidal channel surface area was lost seaward of dikes than landward of dikes for each study area, and reduced or lost channel sinuosity likely leads to diminished channel habitat diversity (Hood 2004). As a result, aquatic species such as Chinook salmon are affected by this loss of habitat.

Effects on salmon functions; effects on bull trout

Weitkamp *et al*. (2000) reported that the filling and channelization of the Green and Duwamish River estuary is likely to substantially impact the Chinook salmon populations because shallow water habitat and migration corridors are reduced, and the simplified estuarine habitat could reduce survival of the portion of the juvenile Chinook salmon populations that remain in estuaries for extended periods of time (e.g., delta fry and parr migrant life history types). Furthermore, the substantially reduced estuarine habitat coupled with a loss of complexity may have resulted in reduced rearing areas and a loss of some life history types (Weitkamp 2000).

In his literature review, Aitken (1998) identified jetties, training walls, filling and dredging as some of the human activities that result in a loss of intertidal rearing habitat and which negatively impact juvenile Chinook and chum salmon through a reduction in one function: feeding and growth. A Canadian study in the Fraser River estuary revealed juvenile anadromous salmonids such as Chinook and chum make use of all tidal channel habitats within the estuary, “and any diking of that habitat would reduce the rearing capacity of the estuary” (Aitken 1998). The degree to which salt water penetrates an estuary, as well as the distribution and circulation of organic materials from outside the estuary, can be altered by jetties and training walls (Aitken 1998). Several studies listed by Aitken (1998) document the potential of these human activities to promote shifts in species assemblages, reduce prey resources, eliminate rearing habitat, and alter migratory behavior.

Research completed by Yates 2001 (NOAA Fisheries unpublished annotated bibliography) at a north Puget Sound channel jetty and causeway concluded that both structures acted as a physical barrier to outmigrating juvenile Chinook salmon because the amount of transitional and shallow habitat often used by these salmon was reduced. In essence, the jetty and causeway acted as barriers and the juvenile Chinook were forced to swim into regions with higher salinity before physiologically prepared (Yates 2001, NOAA Fisheries unpublished annotated bibliography). As such, the physiological transition, migratory corridor, and potentially the feeding and growth and refuge from predators and extreme event functions of juvenile Chinook and chum salmon can be affected. Inaccessibility to pocket estuaries is caused by activities in tidal wetlands such as tide gates, roads, and fill (Beamer *et al*. 2003).

A reduction in habitat complexity via diking and channelization, reduced riparian vegetation, and reduced large woody debris due to agricultural practices and development have impacted anadromous bull trout. Diking of estuaries and floodplains in the Nooksack, lower Skagit, Stillaguamish, and Puyallup regions have obstructed access to historical wetland regions and have affected anadromous bull trout foraging, migration, and overwintering habitat (USFWS 2004). The lower Skagit region was historically a productive salmon rearing region, with sloughs, low-velocity overwintering areas and connectivity, but much of this has been lost. Thus, anadromous bull trout are affected because the period of time these prey species (i.e., juvenile salmon) occupy nearshore environments has been curtailed (USFWS 2004). Sub-adult and adult anadromous bull trout foraging, migration, and overwintering habitat has also been reduced in the Stillaguamish and Puyallup estuaries. Diking, channelization, and development have impacted the Lower Skokomish River and estuary as well. Thus, habitats important to bull trout for foraging, migration and overwintering have been degraded (USFWS 2004). It is also believed anadromous bull trout have been impacted by the decline of forage fish and loss of habitat in Hood Canal and the Strait of Juan de Fuca (USFWS 2004).

Table 4-1. Effects of Loss and Simplification of Estuaries and Wetlands on Ecosystems and Salmon and Bull Trout Functions

Activities	**Effects on nearshore and marine ecosystem processes and habitats**	**Hypothesized effects on salmon and bull trout functions**
Industrial and residential development	• Loss of subaerial wetlands and intertidal areas • Habitat simplification (e.g., channel structure) • Loss of riparian vegetation, LWD • Inaccessibility to pocket estuaries	• Reduced rearing areas • Possible loss of some life history types
Agricultural (diking, filling, tide gates, etc)	• Loss of subaerial wetlands, marsh, and intertidal areas • Altered tidal prism (hydrology) • Altered sediment supply; dynamics • Loss of channels • Loss of organic matter, reduction in detritus • Habitat simplification (e.g., channel structure) • Loss of riparian vegetation, LWD • Loss of tidal channel surface area • Inaccessibility to pocket estuaries	• Altered fish passage • Altered prey species resources • Reduced shallow water habitat and migration corridors • Reduced rearing areas • Reduced feeding and growth • Shift in species assemblage • Altered foraging, migration, and overwintering habitat
Channelization	• Habitat simplification (e.g., channel structure) • Loss of channel sinuosity	• Reduced migration corridors • Reduced rearing areas
Construction (jetties, training walls)	• Loss of intertidal rearing habitat • Physical barrier to migrating salmon	• Reduced feeding and growth • Altered migratory behavior • Reduced rearing areas • Shift in species assemblage • Reduced prey resources • Altered physiological transition • Altered refuge

4.3 Alteration of flows through major rivers of Puget Sound

Stressor: Alteration of flows through major rivers of Puget Sound

Examples of *activities* contributing to this stressor:

- Dams
- Diversions
- Channelization
- "Re-plumbing" of stream and river networks
- Forestry activities
- Development of lands

Working Hypotheses

1. Changes in the timing, magnitude, and quality of flow of freshwater and sediment affects water quantity, water quality and the amount and types of sediments delivered to Puget Sound.
2. Reductions in water quantity can reduce the quantity of useable habitat areas and increase water temperatures. Reduced sediment delivery to estuaries can lead to shifts in aquatic vegetation communities.
3. The effects of these changes on juvenile Chinook and chum salmon include altered feeding and growth (e.g., reduced food sources available to salmon), alteration of refuge locations, and alteration of areas for physiological transition.
4. Dams, diversions and development impact sub-adult and adult anadromous bull trout by impeding or limiting migration, altered hydrology and reduced channel complexity.

A variety of activities have altered freshwater contributions to Puget Sound over the last 150 years. Some examples include the damming of rivers and streams, water diversions, channelization, "re-plumbing" river and lake networks, and reduced groundwater recharge. Consequently the estuarine, delta and nearshore environments are affected in several ways.

Freshwater contributions are an important part of the hydrologic cycle within Puget Sound and are a driving force in controlling the estuarine environment (PSAT 2002). In addition, freshwater inputs directly impact water temperature and salinity, and the vertical and horizontal patterns within Puget Sound for these variables (PSAT 2002).

a) Dams and other flow alteration mechanisms affect runoff timing and peak flows

Effects on processes and habitats

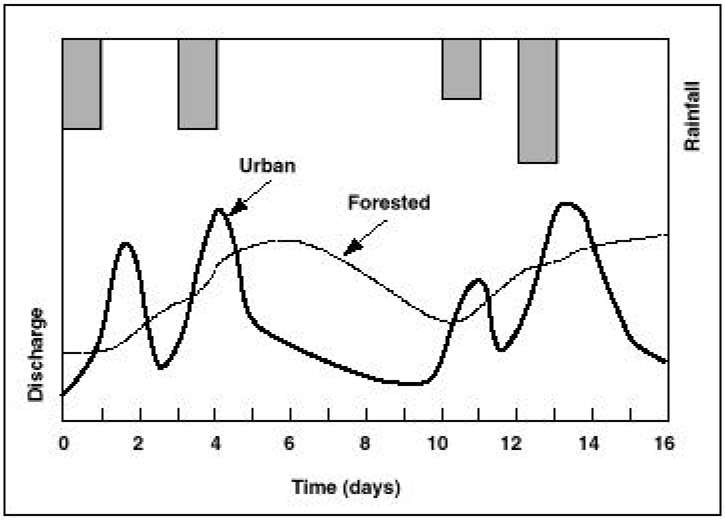
Dams and other flow alteration practices (artifacts of urbanization) can lead to altered freshwater hydrographs, which can affect the quality and quantity of freshwater reaching the estuarine and nearshore environments. Freshwater flows are usually more variable in unmodified rivers as compared to rivers with dams where higher flows are often moderated during parts of the year. Dams and diversions can reduce the magnitude and frequency of elevated flows. Dams and diversions can also affect downstream habitats by altering the distribution of large woody debris (USFWS 2004).

Of the rivers emptying into Puget Sound, the Skagit River discharges the greatest quantity of sediment and the Deschutes River the least (Downing 1983, NOAA Fisheries unpublished annotated bibliography). The size and shape of a delta face are affected when dams prevent the downstream movement of sediments. Cushman dam on the Skokomish River diverts 40% of the annual average freshwater flow from ever reaching the delta (Jay and Simenstad, 1996). Jay and Simenstad (1996) compared pre-diversion (1885) and post-diversion (1941 and 1972) deltaic bathymetric surveys and habitat, implications for the sediment transport regime, and net gain and loss of deltaic surface area and habitat. Their surveys suggested deposition has occurred on much of the inner delta and erosion on much of the outer delta. Many of the historical bathymetric change cross-sections (9 of 12) revealed a steepening of the delta surface, apparently "caused by a loss of sediment transport capacity in the lower river and estuary combined with steady or increased (due to logging) sediment supply" (Jay and Simenstad, 1996). In addition, a 15-19% loss of "highly productive low intertidal surface area" habitat between 0.6 m below MLLW and 0.6 m above was observed, as well as an estimated 17% decrease in area of eelgrass beds. The dams on the Elwha River have impacted the estuary and beach morphology. The recruitment of fluvial sediment has been lost, promoting the erosion of at least 366 meters (1,200 feet) of shoreline between 1939 and 1994 (USFWS 2004).

Forestry and agricultural practices and land development can also contribute to altered hydrographs. Forestry practices such as timber harvest and road building can increase peak flows, as well as increase runoff and decrease infiltration when soils are compacted (EPA 2000). The historical practice of constructing splash dams on streams to facilitate transport of logs downstream also resulted in estuarine impacts (USFWS 2004). Historically, the Samish River contained numerous forks and sloughs within the delta region, all too small to float logs downstream. To facilitate movement of logs downstream, a single channel was created and the remaining channels and sloughs within the delta blocked off (USFWS 2004). In addition, clearing and removal of LWD (and LWD jams) was a common practice in larger rivers such as the Skagit and Nooksack (USFWS 2004). Agricultural practices can affect peak and low flows by increasing storm runoff timing and lowering water tables, respectively (EPA 2000). Finally, development of lands for urban uses can increase impervious surfaces and thereby reduce infiltration, accelerate surface flows to freshwater channels, and generate earlier, larger and more intense peak flows (Figures 4-4 and 4-5) (EPA 2000). This can affect estuarine and shoreline receiving waters.

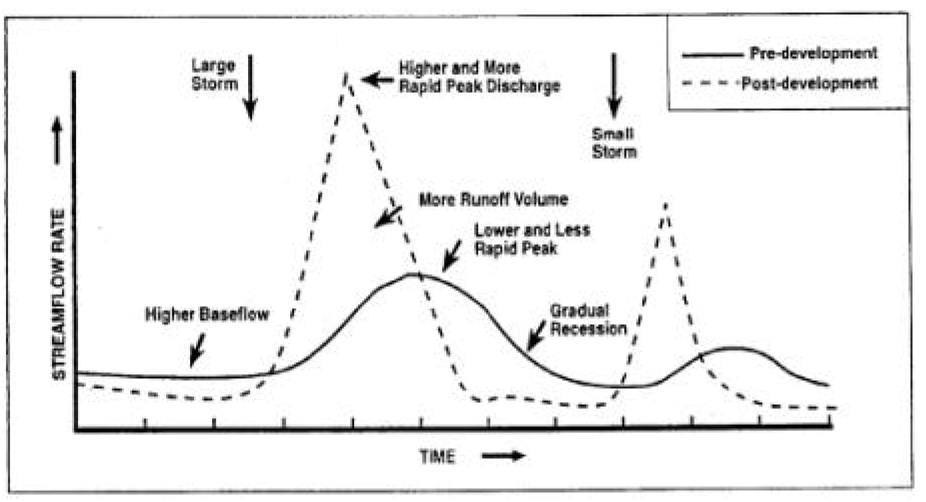
Effects on salmon functions; effects on bull trout

Dam construction can alter estuarine habitat types such as marshes and blind channels in such ways as a loss of marsh and delta surface, and channel erosion and incision of blind channels (K. Fresh, unpublished data). A gradual, or intermediate salinity gradient is especially important in estuaries for juvenile salmon during the rigors of physiological transition from freshwater to saltwater (Aitken 1998). Consequently, the reduced area for transitional salinity concentrations within the delta could negatively impact juvenile salmon such as Chinook and chum when utilizing the delta for osmoregulation functions. Aitken (1998) reported river discharge and surface outflow as one of the four potential factors suggested by the scientific community as limiting the residence time of juvenile salmonids such as Chinook and chum salmon while in estuaries.



Source: EPA Watershed Analysis and Management Project, Hydrology Module, 2000.

Figure 4-4. Difference in response by two different freshwater systems during the same storm event.



Source: Schueler, 1987.

Figure 4-5. Conceptual freshwater hydrographs pre- and post-development.

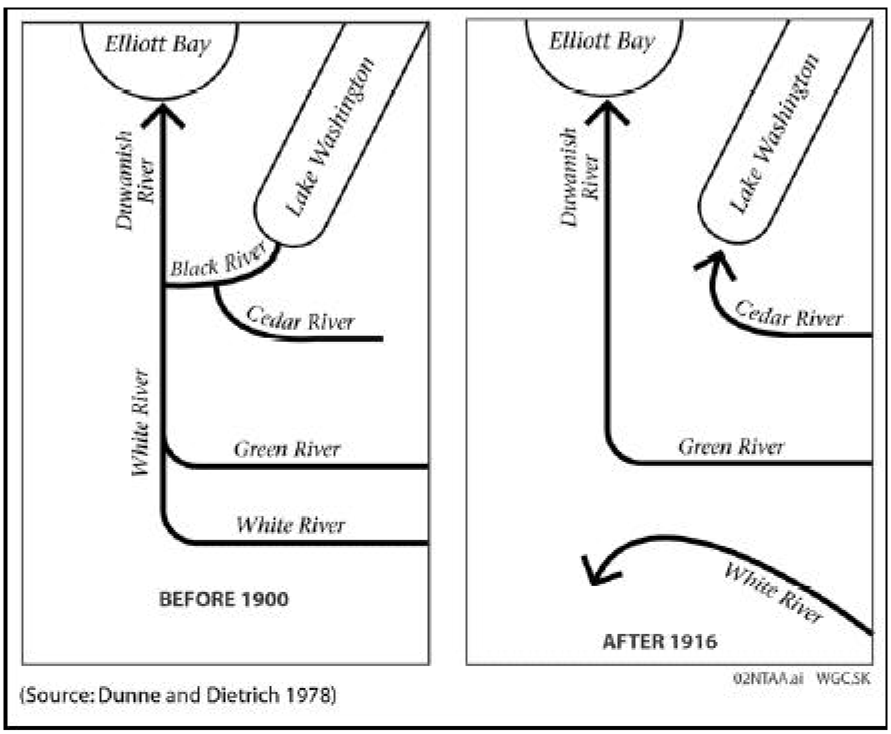
Barriers such as dams limit population interaction "and may eliminate life history forms of bull trout" (USFWS 2004). Population connectivity and viability can be impacted. Dams on the upper Skagit River have prevented the movement of large woody debris to the Lower Skagit River (USFWS 2004). As a result of this and historic wood removal, the habitat complexity in the Lower Skagit River mainstem and estuary has been reduced over time. The practice of repeated splash damming caused channel scouring and long-term impacts to bull trout habitat (USFWS 2004). The Cushman dams on the Skokomish River have reduced the flow of water reaching the delta, and thus affected the sediment regime and the shape of the delta. Consequently, the intertidal zone has been impacted. Biological productivity and the size of eelgrass beds in the Skokomish estuary has been reduced; thus, bull trout are impacted because herring, an important prey species, rely on eelgrass for spawning (USFWS 2004). The loss of eelgrass reduces foraging opportunities for bull trout in the Skokomish estuary (USFWS 2004). The two dams on the Elwha River also have impacted the estuary and eelgrass beds.

b) Re-distribution of flows from Green (to Ship Canal and Puyallup)

Many larger freshwater networks in Puget Sound have experienced moderate to substantial re-distribution of water flow. Such “re-plumbing” of networks has resulted in significant changes to these systems, as well as to associated marine nearshore regions such as estuaries and deltas. See Section 6.8 for a specific example (e.g., re-distribution of flows within the Green/Duwamish River drainage).

Effects on salmon functions; effects on bull trout

Before 1900, more than 4,000 acres of tidal marshes and mudflats once existed where Harbor Island and the East and West Waterways currently stand (King County, 2002). As a result this estuarine habitat has been lost to salmon, and the processes that supply water (in-channel, seeps, groundwater recharge) and sediments to the Puget Sound nearshore, altered. It should be noted however, that juvenile salmonids such as anadromous salmon continue to use available habitats within the estuary, irrespective of the current condition (Von Saunder – abstract from PERS 2004 conference)



Source: King County DNR - WRIA 9 Near Term Action Agenda (2002), after Dunne and Dietrich 1978.

Figure 4-6. Re-distribution of flow in the Duwamish River drainage; prior to 1900 and after 1916.

Table 4-2 Effects of alteration of flows on ecosystems and salmon and bull trout functions

Activities	Effects on nearshore and marine ecosystem processes and habitats	Hypothesized effects on salmon and bull trout functions
Dams	• Reduced frequency of flood flows • Reduced sediment input to estuaries • Temperature and salinity fluctuations	• Reduced delta rearing habitat • Impaired physiological transition
Diversions	• Altered hydrology • Altered sedimentation • Temperature and salinity fluctuations	• Reduced habitat diversity • Altered adult migration pathways • Impaired physiological transition
Channelization	• Increased flow rates • Loss of sediment to deep water • Changes in salinity	• Physical barriers to migration • Loss of rearing habitat • Impaired physiological transition
Re-plumbing of streams and river networks	• Altered salinity profile within estuaries • Changes in delta sedimentation	• Altered or lost historic migration pathways and associated chemical signals
Forestry Activities	• Altered hydrology • Increase in fine sedimentation • Loss of large woody debris recruitment • Temperature increases	• Increased physiological stress • Loss of rearing habitat complexity over time
Development of lands	• Altered hydrology • Increased toxic and nutrient loading leading to eutrophication and hypoxia • Increased fine sediment delivery to estuary • Temperature increase	• Possible lethal and sub-lethal toxic effects • Physiological stress or even mortality in the case of hypoxia

4.4 Modification of shorelines by armoring, overwater structures, and loss of riparian vegetation

Stressor: Modification of shorelines

Examples of *activities* contributing to this stressor:

- Shoreline modifications such as armoring (e.g., by bulkheads, seawalls, groins) to protect property and/or infrastructure (e.g., railroad and road grades);
- Construction of over-water structures (e.g., docks, piers, buildings); and
- Removal of riparian vegetation (e.g., to development [residential, industrial, commercial, roads, railroads], logging, facilitate construction, provide water

views and access, accommodate landscaping) and removal of large woody debris (vessel navigation, fish passage).

Working Hypotheses

1. Armoring of shorelines to protect properties from erosion, constructing overwater structures, and removing riparian vegetation can adversely affect the ability of shoreline habitats to provide food and refuge for salmon.
2. These types of shoreline alterations, which can accompany the development of shoreline properties, affect how sediment, energy, and organic matter move within nearshore areas. Changes in these processes can lead to altered habitat characteristics, which can, in turn, reduce production of prey items for juvenile and adult Chinook and chum salmon and diminish the refuge provided to outmigrant juvenile salmon.
3. Overwater structures affect nearshore habitats by reducing light and organic matter input, altering wave action and sediment transport processes, and adding toxic contaminants. By altering these processes, overwater structures can reduce primary and secondary productivity (via increased shading and reduce organic matter input) and alter sediment characteristics (via altered wave action and sediment transport).
4. Loss or removal of riparian vegetation in the nearshore and estuarine environment alters organic matter and light input, hydrology, and sediment processes, which reduces the delivery of organic matter (affects the detritus cycle), decreases shading (increase in water temperature), and affects water quality via flow alteration and sedimentation. The effects on habitat include a loss or reduction of shoreline vegetation, organic matter, food resources, detritus cycling, large woody debris structure and function, and groundwater. Expected results include an increase in water temperatures, reduced bank stabilization, and altered organic inputs, including the delivery of terrestrial insects to the nearshore, an important food source for juvenile salmon.

Numerous scientific studies have demonstrated the importance of shorelines and nearshore regions to outmigrating Chinook and chum salmon juveniles during early life stages (e.g., see citations in reviews by Aitken 1998; Simenstad *et al*. 1999; Toft *et al.* 2004; K. Fresh, NOAA-Fisheries, personal communication; Weitkamp *et al*. 2000; Haas *et al.* 2002; Duffy 2003). Shorelines and nearshore regions are also important to anadromous bull trout for foraging, growth, migration, and overwintering (USFWS 2004).

Effects on processes and habitats

a) Shoreline Armoring

Thirty-three percent of Puget Sound shorelines have been modified with bulkheads or other types of armoring and half of this amount is associated with single-family residences (PSWQAT 2002a). For the entire state of Washington nearly one half of all shoreline modification is associated with single-family residences (PSWQAT 2002a).

Much of the sediment comprising beaches in Puget Sound results from erosion of coastal feeder bluffs, not sediment delivered by rivers (Macdonald 1995). Armoring to protect shorelines from erosion can adversely affect sediment delivery, sediment transport, and wave energy, all of which determine beach sediment composition (type, abundance and size). A number of authors have discussed the physical effects of shoreline armoring. Macdonald *et al.* 1994 (NOAA Fisheries unpublished annotated bibliography) reports that armoring can lead to the loss of beach area, narrowing of beaches, and lowering of beach profiles. Johannessen (2002) reports that armoring, such as by hard bulkheads, reduces the sediment delivered from bluffs, decreases beach area and bluffs, and decreases backshore vegetation.

Furthermore, shoreline armoring via bulkheads has been shown to deflect waves without dissipating energy (Johannessen 2002; Sobocinski *et al.* 2003), which promotes beach scour and concentrates wave energy to adjacent beaches and backshore areas (Johannessen 2002). Depending on placement of shoreline armoring structures, Macdonald (1995) reported increased turbulence and erosional energy.

Johannessen (2002) showed that bulkheads can increase sediment size on affected beaches, presumably as a result of altered sediment availability and wave energy. Sobocinski *et al.* (2003) found similar results – generally coarser sediments at altered beach sites – in a comparison of altered and natural beaches in central Puget Sound. Others have noted that armoring can contribute to "accelerated erosion of adjacent, unarmored property" (People for Puget Sound 1997).

Lastly, shoreline armoring can alter the input of organic matter to nearshore and estuarine environments. The loss of backshore vegetation and large woody debris adjacent to shorelines are but two effects of shoreline armoring specifically affecting contribution of organic matter (Shreffler *et al.* 1995; People for Puget Sound 1997; Sobocinski *et al.* 2003). In addition, armoring can disconnect aquatic and terrestrial habitats because they can effectively separate riparian and backshore areas from the aquatic environment (K. Fresh, NOAA-Fisheries, personal communication).

In many estuaries and lower reaches of rivers, bank armoring has affected bull trout by degrading and simplifying aquatic habitat, prevented channel migration, altered off-channel habitats, and degraded riparian vegetation (USFWS 2004). Railways and other road networks have contributed to the filling of estuarine habitat and degradation of nearshore habitat (USFWS 2004).

b) Overwater Structures

Overwater structures are one of the more common modifications in the nearshore and can impact intertidal habitats in the nearshore in varying ways. Shading, reduced benthic vegetation, disturbance during pier or dock construction, an increase in re-suspended sediments and turbidity from boat traffic, a change in macrofaunal assemblage, and propeller wash from boat traffic are some of the factors that have the potential to alter the nearshore environment (Haas et. al., 2002). A loss of shallow nearshore land and a change in shoreline slope are also potential impacts. These structures alter important habitat controlling factors such as light, wave energy and substrate (Nightingale and Simenstad 2001). Analysis of Washington DNR's ShoreZone inventory (Nearshore Habitat Program 2001) of information on nearshore resources indicates thousands of overwater structures were present in Puget Sound in the late 1990s to 2000, including 3,500 piers or docks, 29,000 small boat slips, and 700 large ship slips.

Eelgrass habitats are important components of estuarine ecosystems, providing spawning substrate for forage fish such as Pacific herring and critical habitat for numerous epibenthic crustaceans, all of which are important prey species for juvenile salmon (Fresh et al., 1995; Nightingale and Simenstad 2001; Haas et al., 2002) and bull trout (USFWS 2004). Small overwater structures (e.g., single family residence piers, docks, floats) built over eelgrass beds were evaluated by Fresh et al. (1995) to determine if eelgrass density declined underneath and immediately adjacent to several structures in south Hood Canal, San Juan Islands, Bellingham Bay, and Padilla Bay. Results suggested many structures erected over eelgrass beds negatively impacted "local eelgrass densities," with potentially significant amounts of eelgrass lost in areas with large numbers of docks (Fresh et al., 1995). Cumulative losses of eelgrass were considered more significant than losses at individual sites. A loss of eelgrass was also observed immediately adjacent to overwater structures in some areas. Shading was thought to be the major source of impact to eelgrass (Fresh et al., 1995). Gratings to allow light to penetrate through the overwater structures were investigated in this study and preliminary results suggested that impacts to eelgrass were reduced.

Large overwater structures such as ferry terminals can also impact intertidal habitats in the nearshore in varying ways (Nightingale and Simenstad 2001; Haas et al., 2002). Shading and potential impacts to eelgrass, and potential impacts to the epibenthos have been relatively well studied (Haas et al., 2002). These large overwater structures differ from smaller overwater structures due to the frequency of large vessel traffic, thus more frequent propeller wash events leading to an increase in re-suspended fine particle sediments which over time "can lead to a coarsening of the sediments underneath the terminal" (Haas et al., 2002). Scour pits around pilings, flushing of epibenthic fauna, and a reduction of benthic vegetation near terminals due to "bioturbation from sea stars as well as bivalves" are other impacts reported in studies (Haas et al., 2002). Ferry terminals and associated structures have also impacted bull trout by impacting continuity of habitats, as well as degrading nearshore habitat (USFWS 2004). In addition to ferry terminals, large vessels (including container ships, tankers, and cruise ships) docked at port have the potential to affect nearshore habitats. These impacts are probably increasing in recent years. For example, cruise ship traffic has increased markedly since 1999, and to accommodate the increased demand the Port of Seattle added two docking locations in 2004 as well as additional days during the week when ships depart from port (Washington Dept. of Ecology, 2005).

c) Removal of riparian vegetation and large woody debris (LWD)

Analysis of Washington DNR's ShoreZone inventory (Nearshore Habitat Program 2001) indicates that riparian vegetation overhanging the intertidal zone is relatively rare in Puget Sound, occurring at only 440 of the nearly 2500 shoreline miles of Puget Sound. (We have not found a way to estimate the extent to which overhanging riparian vegetation has been lost from the shorelines of Puget Sound). Historically, in the mid-1800's, Puget Sound river bottoms contained dense forests, many of which were hardwoods (Collins et al, 2003). Early records described old-growth forests along shorelines in western Washington (Williams et al, 2001). Since then, much of these forests have been eradicated.

The functions and value of marine riparian zones are not as well known as for those in freshwater systems, however it is believed riparian vegetation serves similar purposes for any body of water they line, and marine riparian zones may provide added and unique functions (Williams et al, 2001). Some of the functions marine riparian vegetation are known or thought to provide to nearshore regions include 1) protection of water quality through pollution and sediment control, 2) wildlife habitat for many species, 3) microclimate and shade, 4) nutrient input, including LWD, and 5) bank stabilization (Williams et al, 2001). The effects of the removal of marine riparian vegetation on processes and habitats includes a shift in community structure, altered microclimate and soil chemistry, increased exposure to sun and wind, and the possibility of an increase in competitive interactions (Williams et al, 2001). For example, removal of riparian vegetation can lead to an increase in contaminants reaching the water (e.g., pesticides and fertilizers) as well as an increase in sediments and nutrients, all of which can lead to eutrophication (William et al, 2001). The removal of riparian vegetation can affect the microclimate due to increased exposure to various elements. This can lead to increased temperatures, increased runoff, decreased moisture, and soil desiccation or erosion (Williams et al, 2001).

Historically, Puget Sound rivers contained dense concentration of wood, but since then much of this wood has been systematically removed from many rivers (Collins et al, 2003). For example, in five northern Puget Sound rivers between 1880 and 1980, 150,000 snags were removed, greater than half from the Skagit River (Collins et al, 2003). In the lower Skagit River alone, 30,000 wood snags were removed between 1898 and 1908 (Collins et al, 2003).

Large woody debris and accumulations are important at multiple scales within large rivers. Wood jams can re-route water and sediment onto adjacent floodplains and deltas; wood jams can also create and maintain channels and sloughs; and wood can form pools (Collins et al, 2003). Large woody debris can be transported to the nearshore by erosion of bluffs and banks, erosion of riverbanks and transport of LWD to estuaries, as well as tidal delivery of drift logs (Williams et al, 2001). Increasing habitat complexity and heterogeneity are critical functions of LWD, "serving particularly important benefits to salmonids in estuarine marshes and nearshore environments" (Williams et al, 2001). The effect of LWD removal to processes and habitats is to reverse those processes and habitats just described.

Effects on salmon functions

a) Shoreline Armoring

When armoring changes substrate types from sand or gravel to cobble, and possibly even to hard structures (e.g., rock or hardpan), it can create conditions that provide inferior habitat for prey resources upon which juvenile Chinook and chum salmon feed (Shreffler *et al*. 1995). Thom *et al*. 1994 (NOAA Fisheries unpublished annotated bibliography) reported changes in community structure is likely a result of armoring, such as a "loss of epibenthic crustacean communities that rely on detritus when fine sediment is eroded to coarser material, or loss of bivalves and larger amphipods when coarse gravel is eroded to bedrock." Furthermore, they reported habitat for benthic species is buried or removed when beach material types are altered.

Sobocinski *et al*. (2003) suggest that the zone producing terrestrial and intertidal invertebrates that are prey for outmigrating juvenile salmon may be negatively affected by armoring as evidenced by relatively poorer invertebrate assemblages in supratidal zones affected by armoring. Thom *et al*. 1994 (NOAA Fisheries unpublished annotated bibliography) reported that food sources required by juvenile salmon such as Chinook and chum are reduced because armoring can alter the processes that transport nutrients and sediments to beaches utilized by salmon and other organisms.

Armoring can also affect prey available for adult salmon by reducing spawning habitat for intertidal-spawning finfish and degrade the quality of habitat for benthic-feeding fish (Thom *et al*. 1994, NOAA Fisheries unpublished annotated bibliography).

Toft *et al*. (2004) suggest that juvenile salmon distribution and behaviors are affected by changes in habitat characteristics (e.g., change in water depth or shoreline slope, substrate type, loss of shallow nearshore, and loss of riparian vegetation) resulting from armoring, with more readily apparent effects when shoreline modifications extended into the shallow tidal zone. Thom *et al*. 1994 (NOAA Fisheries unpublished annotated bibliography) hypothesized that habitat changes related to armoring may force fish to swim into deeper waters where they would be more susceptible to predation.

Toft *et al* (2004) suggested that relatively high juvenile salmonid densities in central Puget Sound locations with modified shorelines were an indication that the fish were forced to occupy deeper regions and form protective schools as adaptations to the habitat changes caused by shoreline modifications.

b) Overwater Structures

Simenstad *et al*. (1999) concluded that while individual over-water structures scattered along shorelines may not significantly impact salmon, the cumulative effect of dense and continuous modifications may affect salmon and salmon recovery efforts. Overwater structures alter underwater light environments, and several studies referenced in Nightingale and Simenstad (2001) document the effects of altered light conditions on juvenile salmonid physiology and behavior. Such effects can alter the behavior of migrating fish and increase the risk of mortality (Nightingale and Simenstad 2001). Studies have suggested altered underwater light conditions in Puget Sound can result in several behavioral changes, including disorientation leading to migration delays, loss of schooling in refugia (i.e., disperse rather than seek refuge in schools), and increased predation risks in deeper waters when migratory routes are altered to avoid changing light conditions (Nightingale and Simenstad 2001). In addition to increased predation risks in deeper waters, feeding capacity can be reduced (Simenstad *et al*. 1999).

Light is also critical to the abundance and distribution of seagrasses such as eelgrass. Important prey resources such as harpacticoid copepods are associated with eelgrass, and any limitation on the extent of eelgrass may impact the availability of prey resources, which can impact migration patterns and survival of juvenile fishes (Nightingale and Simenstad 2001). Prey abundance may dictate the length of residence along shorelines for fish less than 50mm (Nightingale and Simenstad 2001). Studies of small outmigrant juvenile chum salmon in Hood Canal revealed these fish feed significantly on densely concentrated copepods associated with eelgrass (Nightingale and Simenstad 2001). Those areas without eelgrass had much lower concentrations of copepods. In addition, salmon fry growth and residence time are reduced by the occurrence of overwater structures when primary and secondary production are affected; this can limit production and availability of prey (Simenstad *et al*. 1999).

c) Loss of riparian vegetation/LWD

The loss of riparian vegetation can affect salmon and bull trout in numerous ways. With the loss or removal of riparian vegetation, plant and insect food sources can be reduced, and the introduction of contaminants can lead to elevated embryo, juvenile and adult fish mortality, as well as altered growth rates and altered species or community composition (Williams et al. 2001). Shade provided by riparian vegetation is important to the spawning success of surf smelt, an obligate beach spawning species, and shading can reduce mortality attributed to desiccation and thermal stress (Williams et al. 2001). In one study, a loss of shading during summer resulted in higher surf smelt egg mortality at spawning sites as compared to mortality rates at shaded regions (Williams et al. 2001). Finally, vegetated shorelines have been shown to be important contributors of prey resources to juvenile Chinook salmon, but activities such as armoring may lead to a reduced input in these terrestrial prey resources (Brennan et al. 2004). Riparian vegetation produces organic debris that can ultimately form beach wrack, which can then attract a diversity of terrestrial insects and marine invertebrates (Williams et al. 2001). Several studies referenced in Williams et al. (2001) “identified terrestrial insects as a significant dietary component of juvenile Chinook and chum salmon diets in subestuaries and other nearshore waters through Puget Sound.”

LWD contributes nutrients to aquatic environments, and provides refuge, foraging opportunities, and spawning substrate for fish (Williams et al. 2001). Loss of LWD in the nearshore environment can reduce the refuge area for juvenile salmonids such as Chinook and chum salmon (Thom *et al*., 1994, NOAA Fisheries unpublished annotated bibliography).

Effects on bull trout

The primary effects of bank armoring, overwater structures, and removal of riparian vegetation and LWD on bull trout is an impact to foraging, migration, and overwintering habitat (USFWS 2004). Functional estuarine and nearshore habitats are important to anadromous bull trout, especially for foraging and migration, as well as spawning, migration, and rearing of forage fish prey species (e.g., herring, surf smelt, sand lance) important to bull trout (USFWS 2004).

Table 4-3. Effects of shoreline modification on ecosystem processes and habitats and salmon and bull trout functions

Activities	Effects on nearshore and marine ecosystem processes and habitats	Hypothesized effects on salmon and bull trout functions
Shoreline armoring	• Altered sediment and organic matter movement within the nearshore • Altered	• Altered nearshore habitat characteristics • Reduced production of prey items • Diminished refuge for juveniles
Overwater structures	• Reduced light and organic matter input • Altered wave energy regime • Altered sediment transport processes • Possible vector for toxic contaminants	• Reduced primary and secondary productivity • Potential behavioral changes • Potential exposure to contaminants
Removal of riparian vegetation/LWD	• Altered organic matter input • Increased light and temperature • Altered hydrologic and sediment transport processes • Altered groundwater delivery to the nearshore • Reduced bank stabilization	• Increased physiological stress • Reduced viability of summer spawning forage fish • Reduced terrestrial insect recruitment • Reduced refuge opportunities

4.5 Contamination of nearshore and marine resources

Stressor: Contamination due to discharges, chemicals

Examples of *activities* contributing to this stressor:

- Municipal and industrial wastewater discharges
- Stormwater discharges
- On-site sewage effluent discharges
- Oil spill, other hazardous chemical spills
- Cruise ship discharges

Working Hypotheses

1. Discharging or spilling wastes or other materials containing toxic chemicals, nutrients, and/or suspended sediments can expose salmon and bull trout and other organisms to unhealthy concentrations of contaminants and can alter the cycling of carbon and nutrients in these systems. Contamination of nearshore and marine ecosystems in Puget Sound can reduce the ability of the nearshore and marine ecosystems to provide high quality prey items for juvenile and adult Chinook and chum salmon. Altered biogeochemical cycling can diminish the refuge provided to outmigrant juvenile Chinook and chum salmon.
2. Toxic chemicals in the sediments of Puget Sound can expose salmon and other organisms to unhealthy concentrations of contaminants. Toxic contamination of nearshore and marine ecosystems in Puget Sound can reduce the ability of the nearshore and marine ecosystems to provide high quality prey items for juvenile and adult Chinook and chum salmon, and bull trout.

Numerous past and present activities contribute to the contamination of nearshore and marine resources and include, but are not limited to, wastewater discharges from industrial and municipal sources, including cruise ships; stormwater discharges; oil spills, other hazardous substance spills; and on-site sewage effluent discharges.

Nature and Extent of Threat and Impairment

Municipal and Industrial Discharges. In an investigative report published in the Seattle Post-Intelligencer, McClure *et al*. (2002) summarized municipal and industrial discharges in the Puget Sound basin as follows:

- 972 discharges are permitted by the Department of Ecology;
- 180 permit-holders had specific permission to discharge metals, including mercury and copper; and
- Over 1 million pounds of chemicals were discharged to Puget Sound in 2000 by the 20 industrial facilities that reported their releases to EPA.

These discharges originate from a great variety of facilities (e.g., almost 120 sewage treatment plants, more than 300 sand and gravel mines, five refineries) and include a variety of contaminants, including toxic contaminants and nutrients. Ecology's permits typically specify treatment requirements and many also contain limits on concentrations or total amounts of contaminants that can be discharged. Many permits require that dischargers monitor effluent and receiving waters to assess compliance with permit conditions and requirements of the Clean Water Act. McClure *et al.* (2002) noted that approximately one-third of the 8,000 permit violations reviewed by the reporters related to failure to monitor discharges as specified in a permit. Other violations discussed in this newspaper report were for discharging too much of a contaminant or too much wastewater relative to the permitted levels.

Stormwater Runoff. Runoff from urban areas of Puget Sound carries toxic contaminants and nutrients to the region's waterways, including the nearshore waters of Puget Sound. The Department of Ecology has estimated that stormwater is the cause of impairments for approximately one-third of all impaired waterbodies in Washington (cited in McClure *et al.* 2002). Toxic contaminants in stormwater include metals and hydrocarbons running off parking lots and roads and pesticides running off of landscaped areas. Nutrients in stormwater come from runoff of fertilizer and pet waste. (Note: People for Puget Sound are inventorying public stormwater discharges to marine waters and attempting to map stormwater discharges to streams and direct loadings to the marine waters)

Spills. Annually, vessels transport nearly 15 billion gallons of crude oil and refined petroleum through Puget Sound (PSAT 2005). Spills of oil and other materials to the waters and land of the Puget Sound basin can introduce toxic chemicals to Puget Sound. Spills of oil in Puget Sound can also harm nearshore habitats and organisms by directly smothering shorelines. Major spills (i.e., greater than 10,000 gallons) have occurred infrequently in Puget Sound, with a total of 16 of these large spills occurring between 1985 and 2001 (PSWQAT 2002b). Smaller, but still serious, spills in which 25 to 10,000 gallons reach surface waters occur more frequently. From 1993 to 2001 there were 191 of these spills, releasing a total of more than 70,000 gallons in the Puget Sound basin (PSWQAT 2002b). The number of gallons of oil spilled has increased since 2001. In ten years (1993-2003), more than 418,500 gallons of oil have spilled in the Puget Sound basin (PSAT 2005). The most recent spills occurred in 2003 and 2004. In 2003, 4,800 gallons of bunker fuel spilled at Point Wells near Edmonds, with the winds and currents pushing the oil west to Kitsap County beaches (PSAT 2005). In 2004, nearly 1,000 gallons of oil spilled in Dalco Passage between Tacoma and Vashon Island and drifted several miles, fouling beaches, including Quartermaster Harbor (PSAT 2005).

Discharges from vessels. Puget Sound ports are busy with loading and unloading of a variety of large vessels. Discharges from container ships, tankers, cruise ships, tugs and barges, and other vessels at port and while transitting Puget Sound can introduce contaminants to the marine ecosystem. Wastewater discharges from cruise ships are thought to be similar in composition to municipal wastewater (e.g., human sewage and wastewater from commercial operations such as food services and film processing) with additional discharges related to ship's operations. Cruise ships are not subject to the same treatment requirements and permits as shore-based facilities.

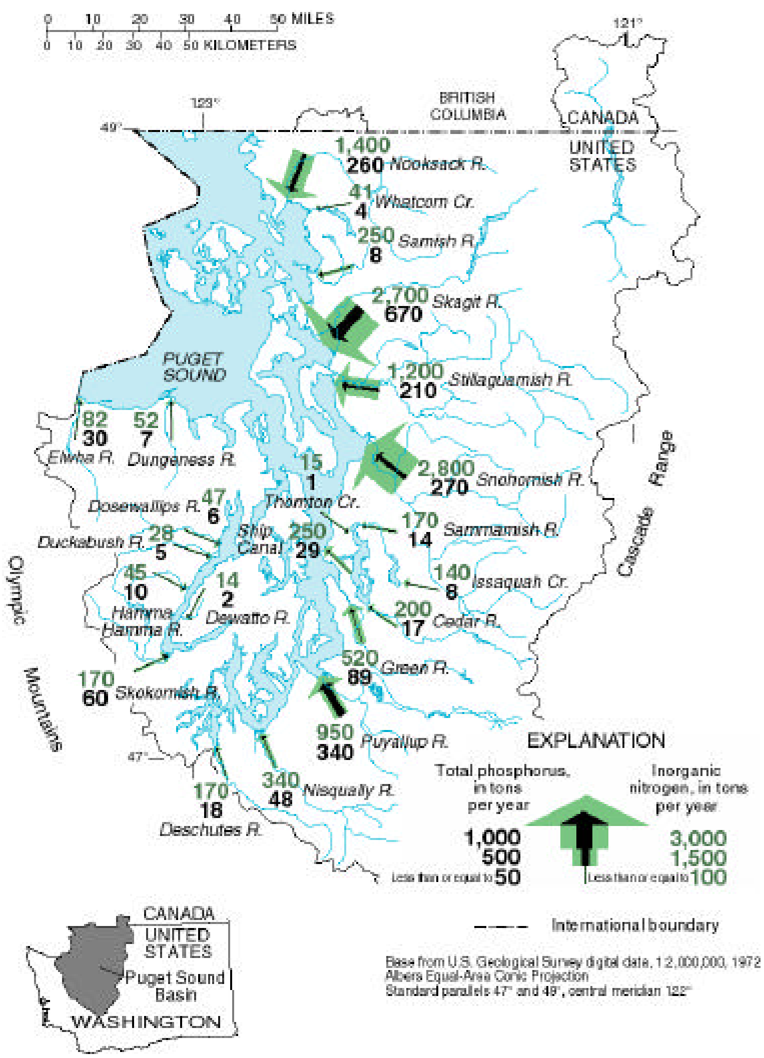
Cruise ships visited Seattle six times in 1999. In 2004, there were 149 port of calls in Seattle by 17 different cruise ship vessels carrying approximately 552,000 passengers (Washington Dept. of Ecology, 2005). The projected number of passengers for the 2005 season is nearly 700,000 (Washington Dept. of Ecology, 2005). In May of 2004 in the Strait of Juan de Fuca, one cruise ship discharged approximately 16,000 gallons of sludge. . In April 2004, an MOU between the Washington Department of Ecology, the Northwest Cruise Association, and the Port of Seattle was signed that prohibits the discharge of black and gray wastewater from cruise ships to Washington waters, except for those vessels with advanced wastewater treatment systems (Washington Dept. of Ecology, 2005). This agreement also specified that a) sludge may be discharged from a cruise ship's advanced treatment system only when more than 12 nautical miles from shore, b) a sampling regimen, with testing and reporting requirements, and c) no dumping of garbage into state waters (Washington Dept. of Ecology, 2005).

On-site sewage systems. PSAT staff estimate that there are up to 500,000 on-site sewage systems in the Puget Sound basin. The quality of effluent from these systems can vary greatly, as can the potential for nutrients or other contaminants to reach surface waters. Based on experiences with fecal contamination of Puget Sound shellfish growing areas, it is apparent that failed systems can impair water quality in local areas of Puget Sound. Loading estimates presented by Fagergren *et al*. (2004) indicate that on-site sewage systems contribute more nitrogen to Hood Canal than all other human sources combined

Nutrient loadings. Nutrients such as nitrogen and phosphorus enter Puget Sound marine environments through freshwater streams and rivers and groundwater seeps to beaches and bluffs. Both nutrients are essential to sustain plant and animal life. However, excess nutrients can cause eutrophication leading to hypoxia (Fagergren et al., 2004).

Historically returning salmon were a more significant sources of nutrients to rivers and streams of Puget Sound than they are in recent years of decreased abundance (Cedarholm et al. 2000, Gresh & Lichatowich 1999, Slaney et al xxxx, and Black & Munn 1999). [S6]Today's loadings of nutrients are shifted in space and time from the historic patterns. We do not have a detailed understanding of the character of historic loads or how the shifts from historic to present-day conditions may affect the nearshore and marine environments of Puget Sound.

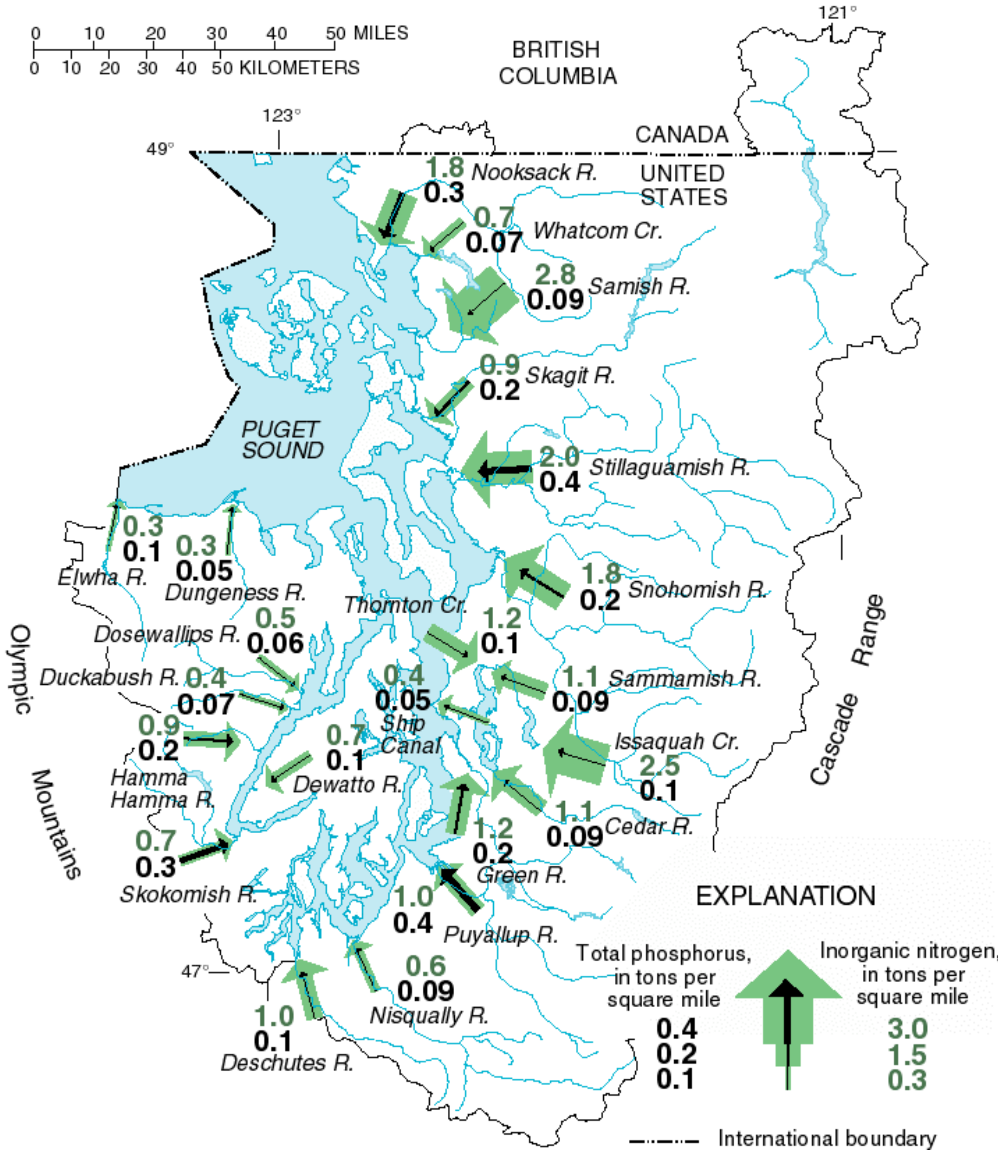
As part of the USGS's National Water Quality Assessment program, Embrey and Inkpen (1998) studied nutrient data from river transport to the Puget Sound Basin from 1980 to 1993. The authors reported an average annual contribution of 11,000 tons of inorganic nitrogen (9,900 tons of organic nitrogen) and 2,100 tons of total phosphorus from major rivers and streams to the Puget Sound marine environment. Major sources of nutrients entering the Puget Sound Basin via rivers and streams include animal manures, agricultural fertilizers and precipitation; wastewater treatment plants are sources of nutrients in urban areas (Embrey and Inkpen 1998). Contributions such as these are tied to land use within the Puget Sound Basin. The greatest nutrient *loads* emanate from rivers and streams exhibiting the largest watersheds and river flow (Figure 4-7). For example, the Skagit and Snohomish Rivers contribute nearly 50% of the nutrient *loads,* and with a combined drainage area of 47% of the Puget Sound Basin (Embrey and Inkpen 1998).



Source: Inkpen and Embrey (1998), USGS Fact Sheet 009-98.

Figure 4-7. Annual nutrient *loads* carried by rivers and streams to the Puget Sound Basin.

Figure 4-8 represents an adjusted picture of nutrient contributions, nutrient *yields*, which allows for the comparison of basins of different sizes. The smallest yields emanate from the Olympic Mountain watersheds and the largest yields are found in basins draining the east side of Puget Sound, with the exception of the Skagit River (Embrey and Inkpen 1998).



Source: Inkpen and Embrey (1998), USGS Fact Sheet 009-98.

Figure 4-8. Annual nutrient *yields* carried by rivers and streams to the Puget Sound Basin.

Effects on processes and habitats

Some contaminants break down at a slow rate, or not at all, and can bind to sediments where they can accumulate in plants and the tissues and organs of animals. Toxic contamination observed in Puget Sound sediments and organisms represents contributions from current discharges and historic loadings. More then 2,800 acres of Puget Sound's bottom sediments are contaminated to the extent that sediment cleanup is warranted because of concerns for toxic effects on benthic organisms (Ecology 2003). Additionally, toxic contamination is observed in the food web of Puget Sound from filter feeders (mussels) to forage fish (herring) to top predators (harbor seals) (PSAT 2002a).

The sea surface microlayer is a region that, as water levels change, various organisms can be repeatedly exposed to high levels of toxic contaminants (PSAT 2002a). The microlayer is important to the egg and larval stage of numerous organisms (PSAT 2002a), some of which may be important prey species for juvenile salmon.

Excess nitrogen loading to sensitive parts of Puget Sound (e.g., southern Hood Canal, Budd Inlet, Penn Cove)might lead to ecosystem changes (PSAT 2002a). Excess nitrogen loadings to these areas can lead to blooms of phytoplankton and subsequent reduction in dissolved oxygen in deeper waters when the blooms decompose..

<u>Effects on salmon functions; effects on bull trout</u>

1. Toxic contaminants from spills, discharges, and contaminated sediments

Various researchers (e.g., O'Neill *et al*. 1998 and Varanasi *et al.* 1992) have shown that Puget Sound salmon accumulate toxic contaminants during their residence in the marine and nearshore environments of Puget Sound. Effects of toxic contaminants on juvenile salmon such as Chinook and chum include: reduced immunocompetence, increased mortality after disease challenge, and reduced growth (Varanasi *et al*. 1993, Arkoosh *et al*. 1991); increased induction of hepatic cytochrome P4501A (CYP1A) and high levels of DNA damage (Stein *et al*. 1995, Varanasi *et al*. 1993); and impaired immunocompetence of juvenile Chinook salmon related to exposure to chlorinated hydrocarbons and PAHs (Arkoosh *et al*. 1994).

Varanasi *et al*, (1992) in research of toxic contaminants in sediments and in other species indicates that the food web for juvenile salmon is contaminated. Recent research from WDFW's PSAMP Fish Component has shown that toxics such as PCBs persist in the Puget Sound food web, and can be found in the tissues of Chinook salmon. It is believed sediments are a sink for legacy toxics such as PCBs, and other toxics, and the food web is a method where Chinook salmon can be exposed to toxics and subsequent accumulation in body tissues (WDFW, unpublished data).

The WDFW researchers have documented that, in general, Chinook salmon living in or migrating through Puget Sound (specifically in central and south sound) are more contaminated with PCBs than stocks outside of Puget Sound (e.g., Columbia River, WA coast). Residence time in the central and southern Puget Sound basins is suspected as a "primary predictor of PCB concentration in Chinook salmon" and as such, those salmon spending the greatest amount of time in central and south sound exhibit the greatest PCB concentrations (WDFW, unpublished data). Another toxic contaminant of concern in Puget Sound is PBDEs, a common chemical that, like PCBs, are found in greater concentrations in resident Chinook salmon versus migratory Chinook salmon. The WDFW researchers report that "this is particularly troubling as the toxic effects from PBDEs and PCBs appear to be additive."

In addition to the direct effects on salmon mentioned above, prey species such as Pacific herring have been found to be "3 to 11 times more contaminated with PCBs in central and south Puget Sound than the Strait of Georgia" (WDFW, unpublished data). These WDFW results from 2004 are similar to those reported in 1999 and 2000 in PSAT (2002a), where body burdens of PCBs were higher in Pacific herring from the central basin (Port Orchard) and southern Puget Sound basin (Squaxin Pass) than Pacific herring from northern Puget Sound and the Strait of Georgia. Finally, the WDFW researchers report that the PCB-contaminated food web of Puget Sound may explain the source of the PCBs identified in southern resident killer whales.

2. Nutrients

Excess nitrogen loading to sensitive parts of Puget Sound might lead to ecosystem changes that might affect salmon prey, refuge, and migration. Nitrogen loadings to sensitive areas can lead to reduction in dissolved oxygen in deeper waters, which might limit production of the food resources for juvenile and adult salmon and affect the distribution of salmon and other organisms in the water column, potentially reducing the refuge and migration functions that would otherwise be provided in these areas. Shifts in the timing and geographic distribution of nutrient loadings as salmon-derived loadings have been replaced by human-derived sources may affect the productivity of marine ecosystems in ways that could affect the production of food for salmon and the function of migration corridors.

Table 4-4. Effects of contamination on ecosystems and salmon and bull trout functions

Activities	**Effects on nearshore and marine ecosystem processes and habitats**	**Hypothesized effects on salmon and bull trout functions**
Municipal and industrial wastewater discharges and cruise ship discharges	• Alters the cycling of carbon and nutrients • Shifts trophic structures and communities of producers and consumers	• Reduces production of high quality prey items • Can diminish refuge opportunities
Stormwater discharges	• Increases concentrations of metals and hydrocarbons • Increases nutrient concentrations which can shift trophic structures and communities of producers and consumers	• Increased sub-lethal and lethal toxicity • Increases potential for hypoxia
On-site sewage effluent discharges	• Increased nutrient loading leading to eutrophication • Shifts trophic structures and communities of produces and consumers	• Increased potential for hypoxia
Oil spill, other hazardous chemical spills	• Multiple potential toxic effects to organisms and food chain through bioaccumulation	• Reduced immuno-competence • Increased mortality • Possible DNA damage

4.6 Alteration of biological populations and communities

Stressor: Alteration of biological populations, communities

Examples of *activities* contributing to this stressor:

- Hatchery releases/introductions
- Harvest
- Aquaculture (Net pens)
- Shellfish aquaculture
- Introduction of exotics

Working Hypotheses

1. Poor finfish aquaculture practices can negatively affect juvenile salmon through increased water quality degradation and introduction of diseases to wild populations.
2. The introduction of hatchery fish into Puget Sound alters biological and natural food web processes, including predator-prey relationships, impacting naturally reproducing populations in several ways. This interaction between naturally reproducing populations and hatchery salmon differs from what occurred historically in Puget Sound.
3. Increased straying rates, interbreeding and genetic effects, and peak localized numbers of fish masking true populations of wild fish have all been documented problems associated with hatcheries. The effects on juvenile Chinook and chum salmon include a reduction in available resources (via an increase in competition for food and space resources), and an increase of predation by hatchery fish on naturally reproducing populations. The resulting reduced resource base, and increased predation rates affect various life history types of many salmon populations.
4. Poor aquaculture practices can negatively affect juvenile salmon through introduction of new aquatic nuisance species and increased competition for a limited prey base in the case of escapes from salmon net pens. Roto-tilling or disking eelgrass beds for preparing clam or oyster beds by shellfish aquaculture operations can significantly alter the biological community.

Food Web Interactions

Salmon using nearshore and marine environments experience varying levels of interaction with other species. Beach seining studies conducted throughout Puget Sound list 50 to 74 fish species present in the nearshore throughout the year (Miller et al., 1977, Brennan and Higgins, 2003). In cases when beach seines are conducted during the peak of salmon migration, juvenile salmon such as Chinook and chum make up between 10 and 30 percent of the catch by number (Brennan and Higgins, 2003). Shiner perch (*Cymatogaster aggregata*) in many seining studies are by far the most abundant resident of nearshore waters (Simenstad et al, 1977, Brennan and Higgins, 2003). The relative abundance, size and diversity of species present in estuarine and nearshore waters at the time salmon co-occur will determine the level of competition for prey and likelihood of predation by larger individuals of those species.

A number of the seining studies focus on salmonids and their specific diet in the nearshore. Stomach contents of Chinook and chum salmon usually include a number of species of terrestrial and aquatic insects, crustaceans, worms and larval fish with epibenthic, neustonic and pelagic associations in the nearshore (EPA, 1991). Very little is known of the diets of other species inhabiting the nearshore at the same time as Chinook or chum juveniles. Miller, et al (1980) group Chinook juveniles in the Strait of Juan de Fuca into facultative planktivores with surf smelt (*Hypomesus pretiosus pretiosus*) and longfin smelt (*Spirinchus thaleichthys*). During a three-year study, juvenile Chinook salmon had variable diets from year to year but consistently contained drift insects. Chum juveniles are described as obligate epibenthic planktivores and share prey items with longfin smelt, Pacific tomcod (*Microgadus proximus*), walleye Pollock (*Theragra chalcogramma*), tube-snout (*Aulorhynchus flavidus*), sturgeon poacher (*Agonus acipenserinus*), shiner perch, striped seaperch (*Embiotoca lateralis*), redtail seaperch (*Amphistichus rhodoterus*) and sand sole (*Psettichthys melanostictus*) (Miller, et al, 1980).

In a south Puget Sound application of the Ecopath model, assumptions about how South Puget Sound functions differently from the rest of the basin oceanographically did not result in changes to the diet of juvenile salmon. Chinook were presumed to consume forage fish, but the importance of terrestrial insects, amphipods and copepods is consistent with other parts of the Sound (Preikshot and Beattie, 2001). Duffy reported less dependence on terrestrial insects in South Sound than North Sound based on the relative difference in freshwater inputs (Duffy, 2003). Duffy also documented that Chinook juvenile prey preferences shifted from epibenthic feeding in delta sites in April and May to planktonic and neustonic feeding in the nearshore marine sites in June and July and piscivory increased with size (Duffy, 2003).

Predation potential for juvenile Chinook and chum salmon in the nearshore is highly dependent on the size at which they enter estuarine and nearshore waters. A study of Chinook smolt predation in Salmon Bay, King County documented predation by cutthroat trout (*Oncorhynchus clarki clarki*), char and staghorn sculpin (*Leptocottus armatus*). Chinook made up 12 percent of the cutthroat diet, 34 percent was made up of other smolts, mostly chum and the remainder primarily sand lance. Char diet was 27 percent Chinook, 12 percent other salmonids and 60 percent other fish. Fifty percent of the staghorn sculpin diet was Chinook. (Footen, 2000 preliminary results)

Nature and Extent of Threats and Impairments

Hatcheries. Approximately 100 state, tribal, and federal hatcheries exist in Puget Sound and the Washington coast (Hatchery Scientific Review Group [HSRG] 2004). Figure 4-9 displays state, tribal, federal and other hatchery locations in Puget Sound. Hatchery production of Chinook salmon in Puget Sound was initiated in the late 1800s (Weitkamp *et al*. 2000) and in 1999, hatcheries released more than 88 million Pacific salmon species and steelhead into Puget Sound and Hood Canal, providing approximately 75% of the harvestable Chinook and coho salmon (HSRG 2004). In Puget Sound, the number of juvenile Chinook salmon released each year has increased from 45 ± 3 million during 1972-1983 to 53 ± 7 million during 1984-1997 (Ruggerone and Goetz 2004). Hatcheries can be production facilities where salmon are produced for tribal and non-tribal harvest, or conservation hatcheries meant to aid in salmon recovery efforts. Myers *et al* (2004) stated that conservation hatcheries should only be temporary measures and not substitute for federal protection under the Endangered Species Act.

Harvest. Direct harvest and bycatch of Puget Sound salmon and bull trout …

Net pen aquaculture. In 2001, 10 commercial net-pen salmon farms were listed as operational in Puget Sound, totaling 131 acres under lease from state, each ranging in size from 2-24 acres (Nash 2001). Four different organizations hold leases for these net pens, and are located in several locations in Puget Sound: outside Anacortes, in Skagit Bay, Rich Passage, Port Angeles, Harstene Island, and Discovery Bay (Nash 2001). In Washington, the farming of Atlantic salmon dominates production at 99%, with the remaining facilities producing coho, Chinook and steelhead trout (Nash 2001).

Shellfish aquaculture. The Pacific Northwest oyster industry saw its beginnings in Puget Sound in the mid-1850s with the harvest of the native oyster, *Ostrea lurida*. Up to 200,000 bushels were being harvested annually from Puget Sound alone (Griffin 1997; Tillamook Bay NEP). By 1895, the stocks were seriously depleted, but the industry was revived with the introduction of the Pacific oyster, *Crassostrea gigas*, from Japan.

Effects on processes and habitats

Effects of hatcheries and harvest are discussed in the next section.

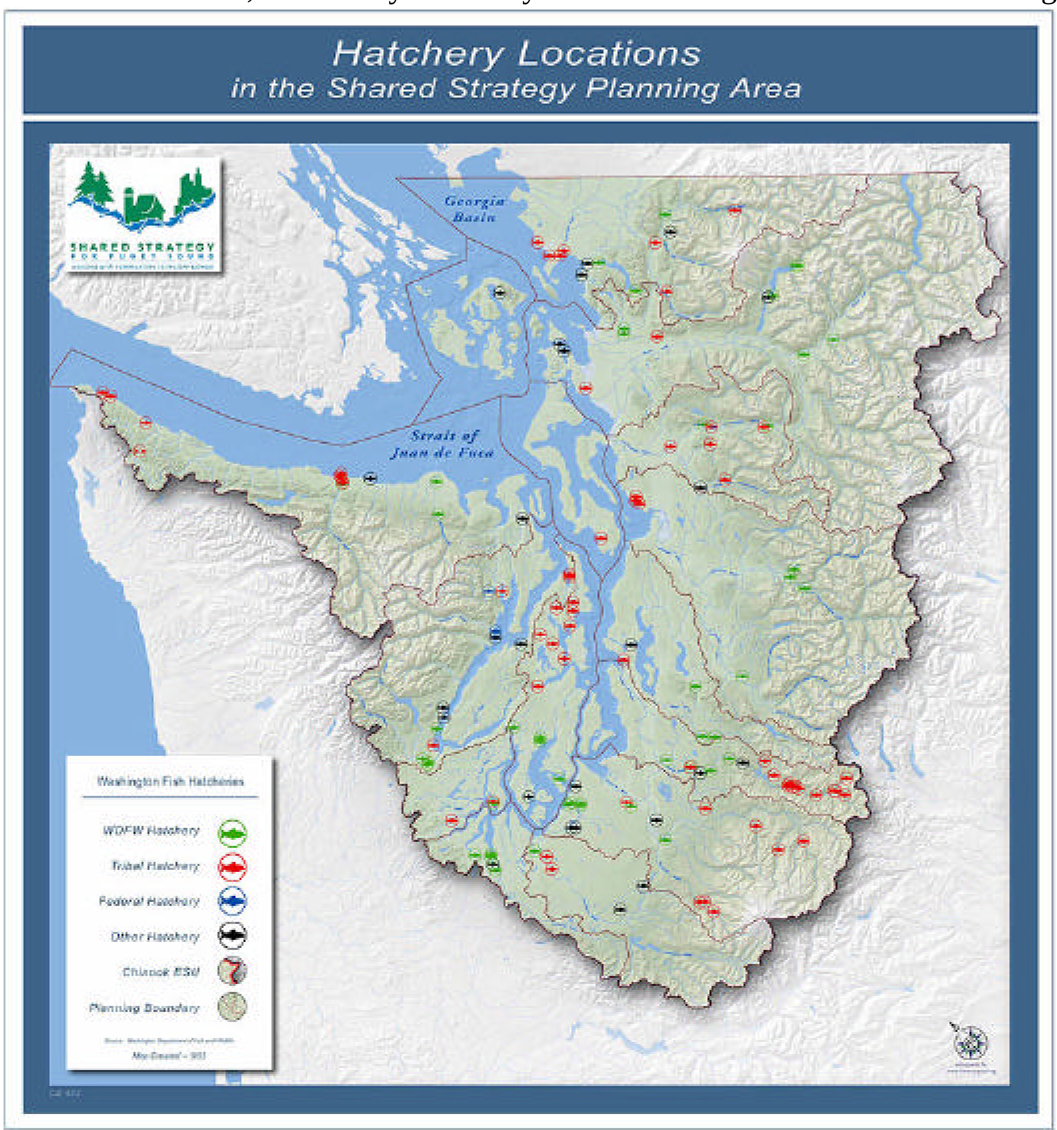
Net pen aquaculture. Fish can escape from aquaculture facilities and become an ecological problem. In the case of salmon farms, fish can escape in small numbers from "operational leakage," and in large numbers from damage to pens due to storms, human error, and so on. Examples of big escapes include an episode of 300,000 salmon escape from a Washington farm in an accident in 1997 (Center for Health and the Global Environment).

Four salmon net pens in the state of Washington in 1997 discharged 93 percent of the total amount of visible solids into Puget Sound (Center for Health and the Global Environment). Discharges from salmon farms can also contain antibiotics and other chemicals that are used to kill salmon parasites.

Shellfish aquaculture. While many attempts have been made by the aquaculture industry to minimize ecological damage from their industry and the industry actively advocates for clean water as a key business need, large-scale aquaculture, if not practiced responsibly, can have detrimental impacts to nearshore habitats.

Recent investigations suggest that commercial oyster farming has a negative impact on eelgrass meadows in Pacific Northwest estuaries.

Several studies referenced by Williams *et al*. (2001) investigating the effect of oyster culture on eelgrass beds concludes that the presence of an oyster farming operation results in decreased eelgrass abundance. These studies have documented decreased shoot density and percent cover, as well as poor natural recovery after the cessation of oyster culture in a given area. Two of the studies within Williams *et al*. (2001) investigated rack and/or stake culture, which may have very different mechanisms and effects than ground



Source: Shared Strategy for Puget Sound

Figure 4-9. State, Tribal, Federal, Other hatchery locations in Puget Sound.

culture. Other studies referenced by Williams *et al*. (2001) investigated the impact of ground culture on eelgrass, and found that ground culture causes a decrease in eelgrass abundance. One study within Williams *et al*. (2001) attributes the decline in eelgrass to dredging oysters during harvest or transplanting of the oysters, but noted a decrease in eelgrass in adjacent, non-dredged control sites as well. This study was the only study to examine dredging impacts. The other studies investigated non-dredging impacts such as shading, competition for space, erosion, and accretion.

A decrease in benthic surface area and direct physical disturbance has been cited as the probable cause of eelgrass depletion at ground culture sites. Off-bottom oyster culture, particularly rack culture, results in shading and either erosion or sedimentation that appear to be the primary cause of eelgrass depletion in those areas. Both rack and stake culture cause a decrease in eelgrass, but stake culture results in an increase in algae such as *Ulva* (sea lettuce) and *Enteromorpha.* These species in turn are suspected of having a negative effect on eelgrass (Griffin 1997; Tillamook Bay NEP).

Culturing species not indigenous to Puget Sound has resulted in a number of unintended introductions, some which have become invasive, including the three aquatic nuisance plant species mentioned below. In 2000, the Washington Department of Natural Resources organized the Puget Sound Expedition to sample Puget Sound for incidence of non-indigenous species. Out of 39 identified species, 24 were indicated to have been most likely introduced in shipments of Japanese or Atlantic oysters (PSAT 2000).

<u>Effects on salmon functions; effects on bull trout</u>

Hatcheries. It is now recognized that hatchery fish may pose potential negative impacts to naturally reproducing populations (i.e., wild fish) (Nehlsen et al. 1991; Aitken 1998: Weitkamp et al. 2000; HSRG 2004; Duffy 2003; Myers et al. 2004). In recent years, hatchery management practices are being reviewed because of faulty assumptions about the level of productivity of nearshore marine waters and their ability to support increasing numbers of hatchery-origin fish. Competition between wild and hatchery fish for a limited prey base became an increasing concern in some parts of the Sound.

Release of salmon from hatcheries introduces a substantial number of organisms that potentially compete with and prey on the region's wild salmon juveniles. King County documented that hatchery Chinook dominate the nearshore (54 to 75 percent of Chinook caught in beach seines) and that hatchery Chinook are larger than wild Chinook and have similar dietary preferences, which suggests a negative competitive interaction with wild fish (Brennan and Higgins, 2003). State and tribal fishery co-managers conclude in the Puget Sound Chinook Salmon Hatchery Management Plan that marine carrying capacity for Chinook may be limited and that recent year's hatchery releases from the Columbia basin exceed the historic high smolt abundance by up to 32 percent.

Myers *et al*. (2004) described brood stock from hatcheries as less adapted to survive in the wild, meaning the fish will usually exhibit poorer survival rates and altered migration and feeding behavior. Hatchery fish do not imprint to natal streams, leading to high straying rates thus distributing genetic makeup that is not locally adapted (Myers *et al*. 2004). The timing of hatchery releases can result in high localized densities, which may mask serious underlying trends in abundance (Weitkamp *et al*. 2000) and well as habitat degradation (Myers *et al*. 2004). In addition, this situation may foster increased predator populations, and with continued or increased harvest pressures, a "concomitant mortality of wild fish" (Myers *et al*. 2004; Weitkamp *et al*. 2000).

Hatchery fish are often larger in body size upon release and will compete with wild fish (Myers *et al*. 2004) for food and space resources during periods of rearing (Weitkamp *et al*. 2000). Aitken (1998) reported a great potential for competition between juvenile wild Chinook salmon and hatchery salmonids (salmon and other non-salmon species such as cutthroat) because of the juvenile wild Chinook salmon's significant dependence on estuaries in Puget Sound and elsewhere for functions such as rearing (i.e., feeding and growth). Large numbers of hatchery fish released during periods coinciding with wild fish outmigrating to Puget Sound may, if densities of hatchery fish are sufficient to deplete local food resources, affect growth of wild juvenile salmon (Duffy 2003).

Juvenile hatchery coho salmon could be a substantial predator of juvenile Chinook and chum salmon in estuarine environments if the timing of hatchery coho releases coincide with naturally reproducing populations of Chinook and chum juveniles while in estuaries (Weitkamp 2000 – draft paper). Duffy (2003) reported releases of yearling hatchery Chinook and coho salmon into Puget Sound may negatively impact naturally reproducing populations.

Harvest. Harvest effects on Puget Sound wild Chinook have been significant over the years. Harvest rates have been set without knowledge of variable ocean conditions and the genetic pressure on wild stocks from overharvesting are just now beginning to be understood.

Harvest interactions have been heavily studied by the co-managers and significant recommended changes will be forthcoming in the Chinook 4(d) rule environmental impact statement (see link below). The Puget Sound Chinook Hatchery Management Plan sets guidelines to integrate harvest and hatchery operations to meet harvest objectives, legal agreements and treaty obligations while keeping within genetic and ecological constraints such as marine carrying capacity. Refer to the following website for more information:
http://www.nwr.noaa.gov/1sustfsh/salmon/PSSalEIS/DEIS/index.html

Net pen aquaculture. Escapees from net pens can compete with and prey on native salmon and diseases and pollutants from net pens can cause infections or toxicity that might impair the marine productivity of the region's salmon and bull trout.

Shellfish aquaculture. Substrate and vegetation disruptions from ground culture of shellfish might affect food production and/or refuge for salmon and bull trout. In addition, introduction of exotic species might affect food resources.

Table 4-5. Effects of alteration of biological populations and communitities on ecosystems and salmon and bull trout functions

Activities	Effects on nearshore and marine ecosystem processes and habitats	Hypothesized effects on salmon and bull trout functions
Hatchery releases/introductions	• Altered food web processes • Increased competition for limited prey base	• Possible genetic effects • Possible disease effects • Possible increased predation
Harvest	• Altered community and food web structure • Reduced nitrogen cycling to terrestrial environment	• Genetic pressure • Reduced resistance to extreme conditions • Direct mortality
Aquaculture (net pens)	• Introduction of diseases • Introduction of non-native species • Possible increased nutrient loading contributing to eutrophication	• Increased susceptibility to disease mortality • Increased competition from escaped Atlantic salmon for breeding and rearing habitat • Potential for localized hypoxia mortality
Shellfish aquaculture	• Potential benthic habitat degradation • Introduction of exotic species	• Reduced native habitat cover

4.7 Urbanization of small marine drainages

Stressor: Transformation of land cover and hydrologic function of small marine discharges via urbanization

Examples of *activities* contributing to this stressor:

- Development (impervious surface expansion)
- Use of chemical pesticides and fertilizers
- Human sewage management

Working Hypotheses

1. The urbanization of smaller independent freshwater drainages (not connected to larger estuaries) in Puget Sound affects water quantity, water quality, and sediment composition, which affect the nearshore habitats (especially pocket estuaries and shorelines) upon which salmon depend. The effects on juvenile Chinook and chum salmon include degraded food resources; lost, degraded, or shifted refuge locations; and lost, degraded, or shifted physiological transition

areas. As a result of these effects on habitat functions for salmon, urbanization of small drainages can affect the viability of fry migrants and delta fry, which might be reliant on pocket estuaries and protected shorelines during flooding of their natal estuaries, life history types of Chinook emanating from areas affected by urbanization.

Nearly 26% of the pocket estuaries that we have identified around Puget Sound are stressed by urbanization. The "landscape function" maps presented in Appendix F illustrate the regionally-evident patterns of urban development along the low elevation streams of the Puget Sound region.

Effects on processes and habitats

Small drainages affected by urbanization experience an increase in the magnitude and frequency of floods, as well as an altered hydrologic cycle (e.g., new peak runoff events) (Figure 4-5) and deliver additional loads of contaminants and sediments to the Puget Sound nearshore (Glasoe & Christy 2004). Increased sediment loads to estuaries may lead to filled-in marsh channels and buried vegetation (K. Fresh, NOAA-Fisheries, personal communication).

Effects on salmon functions; effects on bull trout

Hydrologic alterations, sedimentation, and contamination from urbanization can affect all functions of nearshore habitats of Puget Sound for juvenile salmon. Altered hydrology can affect physiological transition. Sedimentation and contamination can affect refuge and food resources. Fragmentation of functioning habitats by the effects of urbanization can impair migratory corridors

Table 4-6 Effects of urbanization of small marine drainages on ecosystems and salmon and bull trout functions

Activities	**Effects on nearshore and marine ecosystem processes and habitats**	**Hypothesized effects on salmon and bull trout functions**
Impervious surface expansion	• Changes nearshore hydrology, temperature salinity regime • Increases toxicity and nutrient loading efficiency	• Possible sub-lethal and lethal effects • Altered physiological transition functions
Use of chemical pesticides and fertilizers	• Same as spills in Table 4-4	• Same as spills in Table 4-4
Human sewage management	• Same as on-site sewage system in Table 4-4	• Same as on-site seage system in Table 4-4

4.8 Colonization by invasive plants

Stressor: Transformation of habitat types and features via colonization by invasive plants

Examples of *activities* contributing to this stressor:

- Historical introductions
- Continued disturbance
- Nursery escapes

Working Hypotheses

1. Colonization of Puget Sound habitats by invasive plants such as *Spartina spp., Sargassum muticum* and *Zostera japonica* alters natural sedimentation patterns and vegetation assemblages. These changes may reduce the ability of the affected area to provide forage, refuge functions for juvenile Chinook or chum salmon. The extent of the degradation of function is related to the level of substrate modification, the extent of the infestation, and any secondary effects like increased hypoxia or physically blocked channels.

2. Non-native plant species can out-compete native species in high salt marshes, backshore berms and coastal bluffs reducing geologic stability, altering terrestrial insect recruitment and reducing woody debris recruitment.

3. Removing native vegetation, disturbing soils, anchoring over vegetated subtidal habitats and other un-natural levels of disturbance can favor the establishment of invasive species.

Effects on processes and habitats

While over 40 aquatic nuisance species currently infest Puget Sound, *Spartina* and *Sargassum* have transformed more natural shoreline than all others. Each has aggressive growth patterns that out-compete native species. In 2003, *Spartina spp.* infested 770 solid acres of Puget Sound.

Spartina colonization begins when seeds germinate in a mud flat. The seedlings begin to grow vegetatively, forming small circular clumps called clones. These clones then coalesce into meadows, usually fringing and invading the native saltmarsh. *Spartina's* ability to fill an ecological niche in Hood Canal, devoid of predators or higher plant competition, make it capable of growing unchecked. Stout stems and root masses up to five times aboveground biomass promote accumulations of tidal sediments around *Spartina* stands. Sediment accretion takes place three times more rapidly than under normal native conditions. This results in enhanced nutrient levels for the grass clone. Altered nutrient cycles become self-perpetuating, with *Spartina* clones themselves as chief beneficiaries. This allows *Spartina* to out-compete and displace native species.

Sargassum muticum infests 18% of Puget Sound's shorelines (PSAT 2002). *Sargassum* may negatively affect water movement, light penetration, sediment accumulation and anoxia at night (Williams *et al*. 2001). *Sargassum muticum* was introduced to Puget Sound from Japan in the 1940s and patchy or continuous cover has been shown to hold and dominate space in the upper depths of *N. luetkeana* beds, in some cases preventing any re-establishment of the native assemblages that the bed originally supported. *Sargassum* does provide some of the cover structure as native kelps and it is fed upon and colonized by native species, so *Sargassum* arguably is becoming naturalized within the Sound. However, the net change in ecosystem function from the invasion of *Sargassum* is not well understood.

Zostera japonica colonizes unvegetated mudflats, competes with native eelgrass and changes the structure and diversity of the invertebrate community within the sand and mud (Williams *et al.* 2001). The invasion of *Z. japonica* has probably adversely affected the native eelgrass *Zostera marina* at the shallow water limits of distribution. The distribution of *Z. japonica* has not been well documented, but it is known to occur throughout northern Puget Sound (People for Puget Sound, 1997). *Z. japonica* can invade newly created bare patches within native *Zostera* meadows and now occupies formerly unvegetated flats, altering substantially the ecological role of these habitats. (People for Puget Sound, 1997)

Scotch Broom, *Cytisus scoparius,* and Himalayan blackberry *Rubus armeniacus,* are ubiquitous invaders of the lowlands of Puget Sound and is quite prevalent on exposed sandy bluffs, especially where shallow slides expose bare soil. These plants and several other species escaped from nursery culture and produce seeds prolifically or spread by vigorous rhizome growth. Many areas where native vegetation was removed by clearing and soil was disturbed by grading are now infested with these garden escapes to the exclusion of native shoreline species. (Levings, C. and G. Jamieson. 2001), (Manashe, E. 1993).

Non-native submerged plants like Eurasian water milfoil *Myriophyllum spicatum* and emergent plants like purple loosestrife *Lythrum salicaria* while freshwater species, may infest the upper intertidal freshwater marshes within deltas and their adjacent floodplains and within pocket estuaries. These species have the potential to hamper restoration efforts and their ecological effect or specific effects on salmon are not well understood.

Many invasive terrestrial plant species quickly outcompete native plant species for light and soil nutrients thus have the ecological effect of blocking native plant seedling establishment and natural succession. At the time of introduction, many species' potential to become invasive is unknown and it may take years for a newly introduced species to become invasive. Nurseries and garden centers do not always have up to date information on the potential of any plant to become invasive. (Washington Department of Ecology Non-native Freshwater plants website, 2003)

Effects on salmon functions; effects on bull trout

Tidal plant species supplanted by *Spartina* include two eelgrass species (*Zostera marina* and *Z. japonica*) and macroalgae. Loss of mudflat, eelgrass, and macroalgae negatively impacts those fish species that depend on these areas for feeding, spawning, or rearing habitats. Numerous studies have shown that mudflats and eelgrass can be important habitats to juvenile Chinook and chum salmon when rearing in estuarine environments (Thom *et al*. 1989; Aitken 1998; Grette *et al*. 2000; Weitkamp 2000; and Nightingale and Simenstad 2001). Also, one of the most important fixed carbon sources within estuaries, diatom populations, decline dramatically in the dense shade produced by *Spartina*. Declining populations of diatoms could negatively impacts plankton-feeding salmonids such as sockeye salmon (*Oncorhynchus nerka*). (Washington Dept. of Agriculture, 2000)

In the marine riparian area, replacement of native species with invasives may reduce the amount of shade available to beaches affecting forage fish mortality. (Penttila, D. E. 2000)

Table 4-7 Effects of colonization by invasive species on ecosystems and salmon and bull trout functions

Activities	Effects on nearshore and marine ecosystem processes and habitats	Hypothesized effects on salmon and bull trout functions
Historic introductions via aquaculture or erosion control	• Altered community structure • Altered sedimentation regime • Competition with native plant species • Potential to accelerate eutrophication	• Altered feeding and refuge opportunities • Potential mortality from hypoxia
Continued disturbance	• Expanded range of invasion • Replacement of native species with invasives in marine riparian zone may prevent shade tree development	• Reduced access to heavily invaded areas • Increased physiological stress • Reduced terrestrial insect prey
Nursery escapes	• Potential new invasions	• Unknown

4.9 Key Uncertainties and Data Gaps

This section presents an initial list of key uncertainties and data gaps relevant to effects of threats and impairments on salmon and bull trout in nearshore and marine environments.

A synopsis produced by Anne Shaffer (WDFW) from the *Salmon in the Nearshore* session of the Pacific Estuarine Research Society (PERS) Annual Meeting in 2004 identified the following data gaps relevant to sections 4.1 through 4.8: comprehensive nearshore sediment quality and toxicity; and hatchery monitoring and, specifically, consistent marking of all hatchery fish.

Disucssions with our technical advisors (Kurt Fresh and Bill Graeber) suggested the following additional data gaps relevant to this section:

- The processes by which natural and human perturbations affect nearshore ecosystems and salmon functions;
- Identify historic pocket estuary distribution across the Puget Sound landscape and learn about Chinook spawning in these systems
- Continued research in the relationship between toxic chemicals (e.g., PCBs, PBDEs), legacy sediment contamination and the food web, spatial distribution in Puget Sound, and how this affects Chinook salmon while in the Puget Sound basins;
- Studies on the effects of habitat alteration from aquatic nuisance species;
- Aggregate ecological indicator scoring approach (much like what was done for Bainbridge Island). Drift cell overlay with a host of physical and chemical stressors.

- More research to better understand the historical nutrient template with respect to salmon's importance as a pathway for loading of nutrients to nearshore and marine habitatshabitats and the shift in time and space as human sources have come to dominate loadings in some parts of Puget Sound.

4.10 Assessment Of Existing Management Actions

A number of existing state, local and federal programs can contribute to recovery of salmon populations by protecting and restoring nearshore and marine environments. This section provides a brief introduction to a number of these management programs.[1]

4.10.1 Comprehensive conservation and management for Puget Sound

Puget Sound is an estuary in the National Estuary Program and, as such, is subject to more detailed management than other coastal areas through a comprehensive conservation and management plan (CCMP). The CCMP for Puget Sound is the Puget Sound Water Quality Management Plan, amended most recently in 2000 by the Puget Sound Action Team, a broad partnership of entities involved in protecting and restoring Puget Sound and whose membership includes executives of key state and federal agencies. The goal statement for the Plan's Marine and Freshwater Habitat protection program is:

> *To preserve, restore and enhance the ecological processes that create and maintain marine and freshwater habitats and to achieve a net gain in ecological function and area of those habitats within the Puget Sound basin.* – Puget Sound Water Quality Management Plan adopted December 14, 2000.

This goal statement acknowledges the historic loss of marine and freshwater habitats throughout the basin and adopts the prevailing wisdom of achieving restoration of habitats by addressing the underlying processes that create and maintain them. In the first few years of implementation, this philosophy has worked its way into the lexicon of some of the region's permitting programs and is reflected in recent guidance documents such as the Shoreline Guidelines rule promulgated by Ecology for updating Shoreline Master Programs and the watershed and nearshore guidance documents for Shared Strategy.

4.10.2 Shoreline Management Act (SMA)

Implemented by local governments and subject to state Department of Ecology approval, the SMA requires all local governments to update their Shoreline Master Programs

[1] This is by no means an exhaustive treatment of the management actions currently in place in the Puget Sound basin. We have focused on authorities for management actions by state and regional entities. We have not included summaries of incentive and/or education programs in this section. Such programs exist and are effective in contributing to protection by encouraging desired behaviors, investments, etc. but we have not had a chance to prepare summaries for this document. When this document is integrated with local chapters into the full regional recovery plan, we expect that a more complete depiction of existing management will be portrayed.

(SMPs) consistent with Ecology's new shoreline guidelines. Local SMPs contain policies, regulations, and permitting and compliance provisions addressing all shoreline use and development activities. The guidelines establish a new standard for local SMPs that requires use of the latest scientific and technical information to demonstrate that new shoreline growth and development will result in "no net loss of shoreline ecological functions". Local governments receive state funding and must base their updated SMP policies and regulations on a comprehensive inventory and assessment of shoreline ecological processes and functions, cumulative impacts and a restoration plan for shorelines that currently have degraded or impaired functions. Additional guidelines provisions establish minimum standards for all types of over water structures and shoreline modifications (reducing the number and extent of impacts from new breakwaters, jetties, groins, and bulkheads, piers and docks, dredging and fill), wetlands, vegetative buffers and structural setbacks, new residential subdivisions adnd mining activities, again, all aimed at achieving no net loss of shoreline ecological functions.

All local governments fronting on marine and Puget Sound waters are subject to SMA requirements. Therefore, the SMA provides an important tool for protecting and restoring the near shore and marine habitat upon which salmon depend.

4.10.3 Hydraulic Code

Pursuant to the Hydraulic Code, the Department of Fish and Wildlife issues Hydraulic Project Approvals (HPAs) for shoreline construction that would affect the bed or flow of a waterbody. The aim of the permit program is to protect fish life. Individual Fish and Wildlife biologists generally negotiate project designs, construction methods and timing to minimize the impacts to fish within the permit area. While the department asserts that no net loss of habitat function is achieved for each permit, the hydraulics code does not specifically address the landscape perspective of nearshore processes so lot by lot mitigation requirements are generally not adequate to prevent further degradation. Further, the Hydraulic Code RCW 77.55 allows single-family residences on marine beachfronts to locate bulkheads up to 6 feet waterward of the ordinary high water line. While the same section of the code prevents permanent loss of critical food fish or shellfish habitats, the effect on forage fish, which spawn in the upper intertidal zone may be severe over time as more waterfront properties become developed applying this maximum allowance.

4.10.4 Growth Management Act (GMA)

The State of Washington's Growth Management Act (GMA) is implemented by local comprehensive plans, critical areas ordinances, natural resource designations and development regulations. These policies, designations, and regulations are created, maintained, updated and enforced by each local government jurisdiction and under the direction of the state's Department of Communities, Trade and Economic Development (CTED).

GMA planning goals include conservation of fish and wildlife habitat and protection of the environment and enhance the state's hiqh quality of life, including air and water quality and the availability of water (RCW 36.70A.020).

The GMA requires the designation and protection of critical areas to protect the function and values of critical areas and specifies that these designations and protections should include special consideration to conservation and protection measures necessary to preserve or enhance anadromous fisheries (RCW 36.70A.172). Administrative code promulgated by CTED enumerates critical areas as wetlands, aquifer recharge areas, frequently flooded areas, geological hazard areas, and fish and wildlife habitat conservation areas (WAC 365-190-080). This code also specifies that local implementers (1) provide evidence that they have given special consideration to conservation or protection measures necessary to preserve anadromous fisheries and (2) include measures that protect habitat important for all life stages of anadromous fish and address stream flows, water quality and temperature, spawning substrate, instream structural diversity, migratory access, estuary and nearshore marine habitat quality, and the maintenance of salmon prey species (WAC 365-195-925).

GMA critical areas ordinances are being updated over the next two years and are required to include best available science for protecting those areas with special emphasis on anadromous salmonids. Action Team staff and partner agencies are currently involved with Puget Sound counties to result in stronger nearshore protections through this process. Best available science, including studies cited in this and other Shared Strategy documents, proceedings related to the Puget Sound Nearshore Ecosystem Restoration Project and other sources are forming the basis of these reviews and updates.

4.10.5 Aquatic Lands Act

The Department of Natural Resources (DNR) manages approximately 2 million acres of aquatic lands in Puget Sound consisting of tidelands, shore lands and bedlands on behalf of the citizens of the state. The lands are managed to provide a balance of public benefits that are varied and include encouraging direct public use and access, fostering water-dependent uses, ensuring environmental protection and utilizing renewable resources. Generating revenue consistent with the above benefits is also a public benefit. The DNR has several programs that provide management opportunities for salmon recovery in the nearshore and marine waters:

- Management of leases and easements for use of aquatic lands – each lease or easement can be conditioned to address specific environmental issues. DNR can withdraw specific aquatic lands from being available for leasing.
- Aquatic Reserves Program – DNR has developed an Aquatic Reserve Program that will ensure environmental protection of the unique habitat features at sites nominated by external entities, reviewed by a technical advisory group, and final review by the Commissioner of Public Lands.
- The DNR in partnership with The Nature Conservancy has initiated a new conservation leasing program.

- Currently, an assessment of how DNR's proprietary actions affect species that are protected by the Endangered Species Act is currently underway which will lead to the development of a Habitat Conservation Plan.
- Establishment of Aquatic Reserves – the DNR can withdraw an area from leasing and designate it as an aquatic reserve to protect unique habitat features.
- The DNR has the lead on monitoring seagrass in Puget Sound through the Puget Sound Ambient Monitoring Program and is partnering with the University of Washington in monitoring biotic communities on tidelands in south and central Puget Sound.
- The DNR is funding aquatic lands restoration projects.

4.10.6 Corps of Engineers permits under the Clean Water Act and Rivers and Harbors Act

These permits, since they are federal actions, are subject to consultation with NOAA and US Fish and Wildlife Service for any impacts to ESA listed species. Like the local and state permits, however, they are considered on an individual project basis and avoidance, minimization and compensatory mitigation do not consider the landscape context, protecting natural processes or additive impacts.

4.10.7 National Pollutant Discharge Elimination System (NPDES) permits

These federal permits for discharges to surface waters are in most cases delegated to the state Department of Ecology. The monitoring and reporting requirements of each permit are performed by the permittee (self-reporting). These permits cover discharges of municipal and industrial wastewater and stormwater. The strategy for this program is to slowly reduce the effect of overall loading of wastewater through 5-year reviews of each permit based on the initial year the permit was granted. In many cases, however, increased volumes and toxicity of discharges have been allowed in successive phases. These permits are subject to increased restrictions if ambient water quality monitoring reveals that certain pollutant constituents are exceeded within the receiving waterbody.

4.10.8 Other regulatory programs

There are a number of other programs that aim to protect against stressors discussed in this section. This subsection addresses two such programs: spills prevention and response and dredged materials management

Spill prevention programs were recently augmented by stationing a rescue tug at Neah Bay designed to respond to vessels that lose power while approaching port. However, the entire spill response network should be improved to prevent and respond to any oil, chemical or other spills that would affect salmon VSP.

Dredged material management programs require testing and avoidance of contaminated sediments that could be re-suspended by dredging and mapping of any new hot spots.

4.10.9 Acquisition and restoration programs

Protection via public acquisition of important features of Puget Sound's shoreline began shortly after 1964 under the State's Land and Water Conservation Fund (LWCF) Bond Program. Established by citizen Initiative 215 in 1964, the Interagency Committee for Outdoor Recreation (IAC) helps finance recreation and conservation projects throughout the state. Both state and federal wildlife agencies have purchased nearshore habitat lands as wildlife management areas. The Nisqually, Dungeness and San Juan Islands National Wildlife Refuges and the Fir Island State Wildlife Management Area are notable nearshore acquisitions that protect thousands of acres of diverse habitat types and their associated species.

Additional state funding programs for conservation include the Washington Wildlife Conservation Fund (WWCF), Aquatic Lands Enhancement Account (ALEA), and Salmon Recovery Funding Board. These are combined with a number of federal grant sources such as North American Waterfowl Conservation Act (NAWCA) grants and Coastal Wetland Planning, Protection and Restoration Act (CWPPRA) grants administered by the US Fish and Wildlife Service. These government-funding sources are matched with local contributions to purchase lands along the nearshore, associated wetlands, low elevation riparian areas and uplands that protect nearshore habitats.

The rate of acquisition for conservation purposes by these partners has varied throughout the years and is largely dependent on the size of appropriations and availability of properties for sale. From 2000 to 2003, the rate of nearshore habitat acquisition has been approximately 3,200 acres per year (PSAT 2003). The general trend has been that properties containing shorelines and other aquatic habitats in rural areas are less expensive and more available than those same types of properties in developed areas. As population increases throughout the basin, competition between conservation and development is expected to increase. It is expected that within the next 50 years, most of the available undeveloped waterfront property will either be conserved through acquisition or restrictive covenant or developed.

Many of the funding sources and programs listed for nearshore acquisition above are also meant and used for restoration. The breadth of forces degrading nearshore habitat can be remediated through restoration of one kind or another. From 2000 to 2003 restoration projects such as dike breaches in estuarine marshes, levee set backs along lowland floodplains and riparian corridor reestablishment averaged approximately 1,200 acres per year (PSAT 2003). In the face of continuing alterations to Puget Sound's shorelines and estuaries, it is unlikely that protection efforts will avoid or mitigate all future loss or degradation of nearshore habitat and functions. Therefore, restoration must be planned to address cumulative impacts of land development and other human activity.